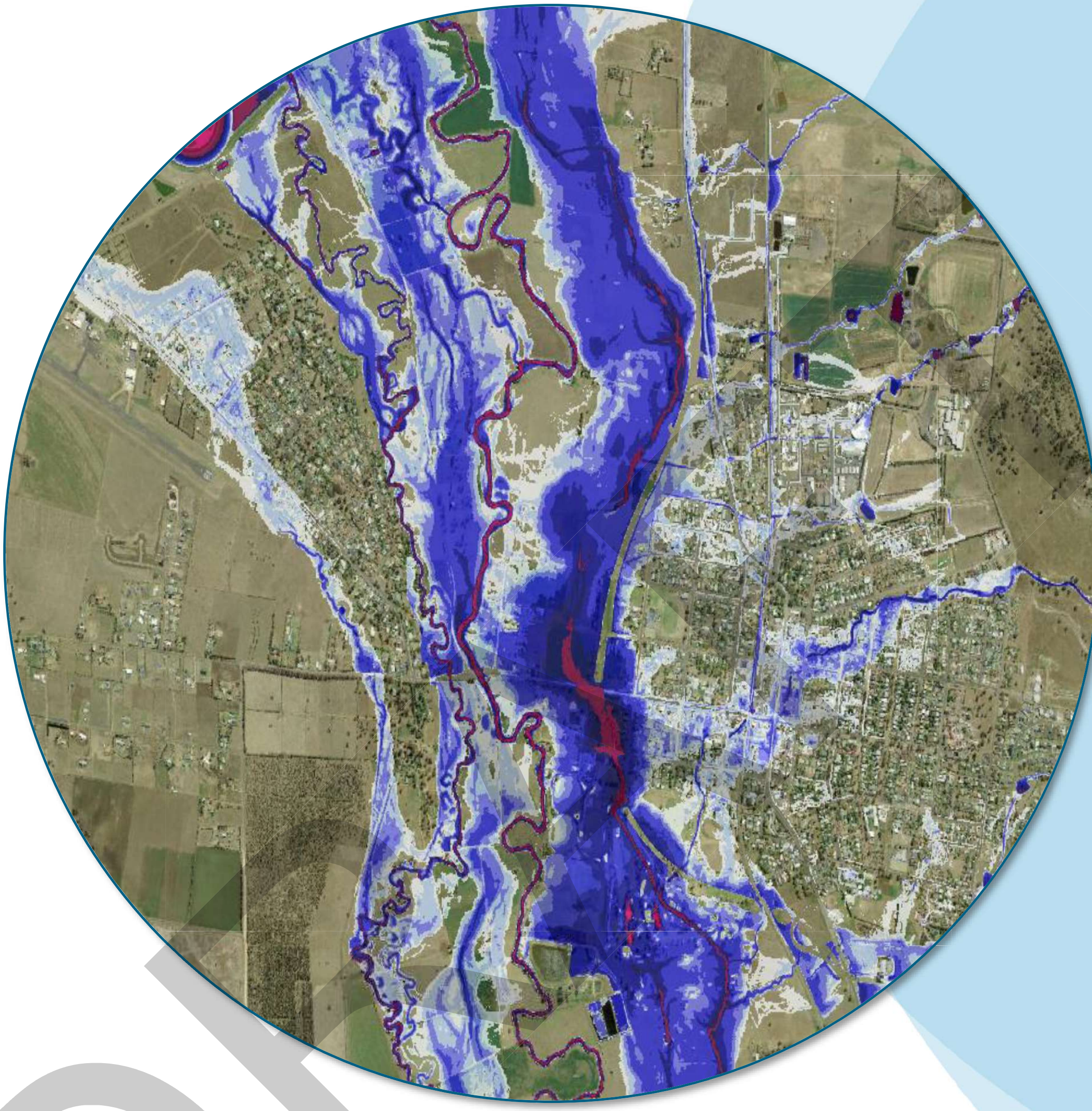


Scone Flood Study

Upper Hunter Shire Council

May 2024

Level 17, 141 Walker Street
North Sydney NSW 2060

Revision 0 – Draft Report for Client Review

rp311015-00018lt_crt230420-Scone FS Rev 0

This page is intentionally blank

Upper Hunter Shire Council
PO Box 208, Scone NSW 2337
council@upperhunter.nsw.gov.au
(02) 6540 1199

311015-00018 – Scone Flood Study

Rev	Description	Author	Review	Worley Consulting Approval	Date
A	Draft Report for Internal Review	LT L To	CRT C Thomas	CRT Chris Thomas	24-05-2024
0	Draft Report for Client Review	LT L To	CRT C Thomas	[signature] Chris Thomas	27-05-2024

This page is intentionally blank

Table of Contents

List of Figures

List of Tables

Executive Summary

[TO BE FINALISED]

1. Introduction

Scone is located within the Upper Hunter Shire Council Local Government Area (LGA) in the Hunter Region of New South Wales (*refer* **Figure 1-1**). The three major waterways of Middle Brook, Kingdon Ponds and Parsons Gully lie immediately west of the Scone township and drain a catchment area upstream of Scone of about 360 km^2. These three waterways separate Scone from the satellite suburb of Satur, which is located to the west.

The catchment has a history of flooding, with inundation to private and public property in proximity to the major waterways. Flooding of Middle Brook, Kingdon Ponds and Parsons Gully would inundate the rural areas between Scone and Satur, overtopping Liverpool Street in major flood events and isolating Satur. Properties on the western edge of Scone would also be inundated during a flood event along these watercourses.

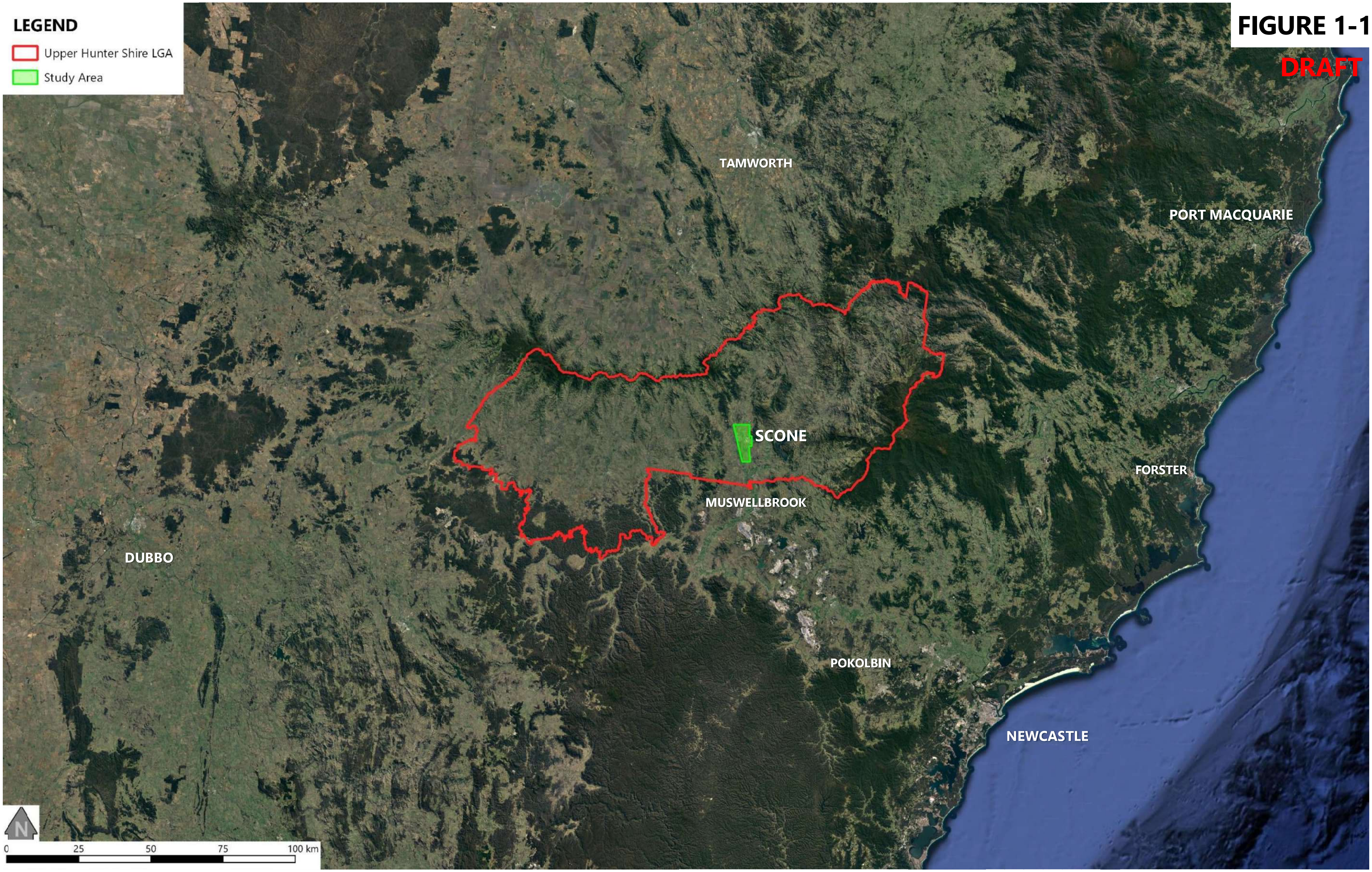
Figtree Gully originates in the hills to the north-east of Scone and traverses the town before discharging into Parsons Gully to the south of the White Park Equine Complex. Figtree Gully drains an area of about 7 km^2. The Figtree Gully system within the Scone township only has a limited flow conveyance capacity. Floodwaters escaping the confines of the channel would inundate residential and commercial properties, including businesses in the Scone Central Business District.

Upper Hunter Shire Council (Council) is responsible for local planning and land management within its LGA, including the management of flood prone land. Previous floodplain risk management activities completed by Council in the study area have included the *Scone Flood Study* (*DLWC, 1996*), and the *Scone Floodplain Risk Management Study and Plan* (*Bewsher Consulting, 1999*).

Council engaged Worley Consulting (*part of the Worley Group*) to undertake an updated Scone Flood Study. The update was requested in response to various factors including recent improvements in flood modelling technology, the availability of new data, changes in the catchment associated with recent developments and the need to assess the potential implications of climate change on local flood behaviour.

The study provides an improved understanding of the potential impacts of floods on the local community and will form a basis for the ongoing management of flood risk in the Scone catchment. The study has been undertaken in accordance with the NSW Government's *Flood Prone Land Policy*, the primary objective of which is to reduce the impact of flooding on individual owners and occupiers of flood prone land, and to reduce private and public losses caused by flooding. New hydrologic and hydraulic flood models have been developed as part of the review adopting the latest available data for the catchment, and up-to-date guidelines, practices and techniques.

FIGURE 1-1



Prepared by: worley consulting

SCONE STUDY LOCATION

2. Background

2.1. The Need for Floodplain Risk Management

Floods are part of the Australian landscape. They occur in many parts of Australia, and their severity and causative mechanisms may vary widely between locations.

While floods have positive impacts such as providing inflows to water supplies, sustaining flood-dependent ecosystems and improving soil moistures and fertility for farming, where humans have occupied the floodplain they pose significant risk to life and property. Negative impacts of flooding include human fatalities and injuries, economic damage, environmental damage, and disruption of individuals' lives and the function of communities (*AEMI 2014*).

Historically, flood damage in Australia is greater than that of any other natural hazard, and flood-related deaths are a continuing occurrence. Despite the hazard posed, flooding is the most manageable natural disaster, as its behaviour and potential extent can be estimated and considered in decision making. In New South Wales, the management of flood liable land is governed by the NSW Government's Flood Prone Land Policy, the main objective of which is to reduce the impact of flooding and flood liability on owners and occupiers of flood-prone property and reduce public and private losses from flooding. The policy also recognises the benefits of the appropriate and sustainable use, occupation and development of flood-prone land.

Studies such as the Scone Flood study are undertaken to help local government make informed decisions about managing flood risk by using detailed flood models to quantify flood characteristics and flooding patterns. At a later stage, the update of the Scone Floodplain Risk Management Study will also be undertaken. That study will investigate options to manage and alleviate flood risk including potential property, flood and response modification measures.

2.2. Study Area

The main urban areas included in the study area are Scone and Satur. The Scone Central Business District (CBD) is located along Kelly Street between Susan Street to the north and Kingdon Street to the south. The main residential areas of Scone are located to the east of the CBD, while new residential developments are planned for the south-east fringe of the town. The township covers an area of about 4 km^2. The recently completed Scone Bypass runs along the western edge of the town.

Satur is a satellite suburb of Scone which is located about 1 kilometre to the west. Satur covers an area of about 1 km^2 and comprises primarily residential lots. The Scone airport is located near the north-western corner of Satur.

The study area also comprises the floodplains of Middle Brook, Kingdon Ponds and Parsons Gully. These waterways generally flow from north to south past Scone and Satur before discharging into the Hunter River south of Aberdeen. They originate in the mountainous areas to the north and north-east of Scone, which are characterised by steep slopes and is largely forested. The flatter floodplain areas are typically rural landholdings with grassed cover. Kingdon Ponds in particular comprises a large number of meander bends between Wingen and Scone.

Middle Brook, Kingdon Ponds and Parsons Gully share a common floodplain in the vicinity of Scone, with no clear catchment divide between the three watercourses. Flows which break out of one of these watercourses would be conveyed by the other neighbouring watercourses.

Figtree Gully originates in the hilly undeveloped area to the east of Scone and traverses the town in a north-east to south-west alignment. Figtree Gully is an open grassed channel between Barton St to the east and Park Street to the west. Downstream of Park Street, the watercourse transitions into a concrete channel through the Scone CBD. Figtree Gully transitions back into an open grassed channel near Kingdon Street and runs in a southerly alignment through White Park Equine Complex before discharging into Parsons Gully.

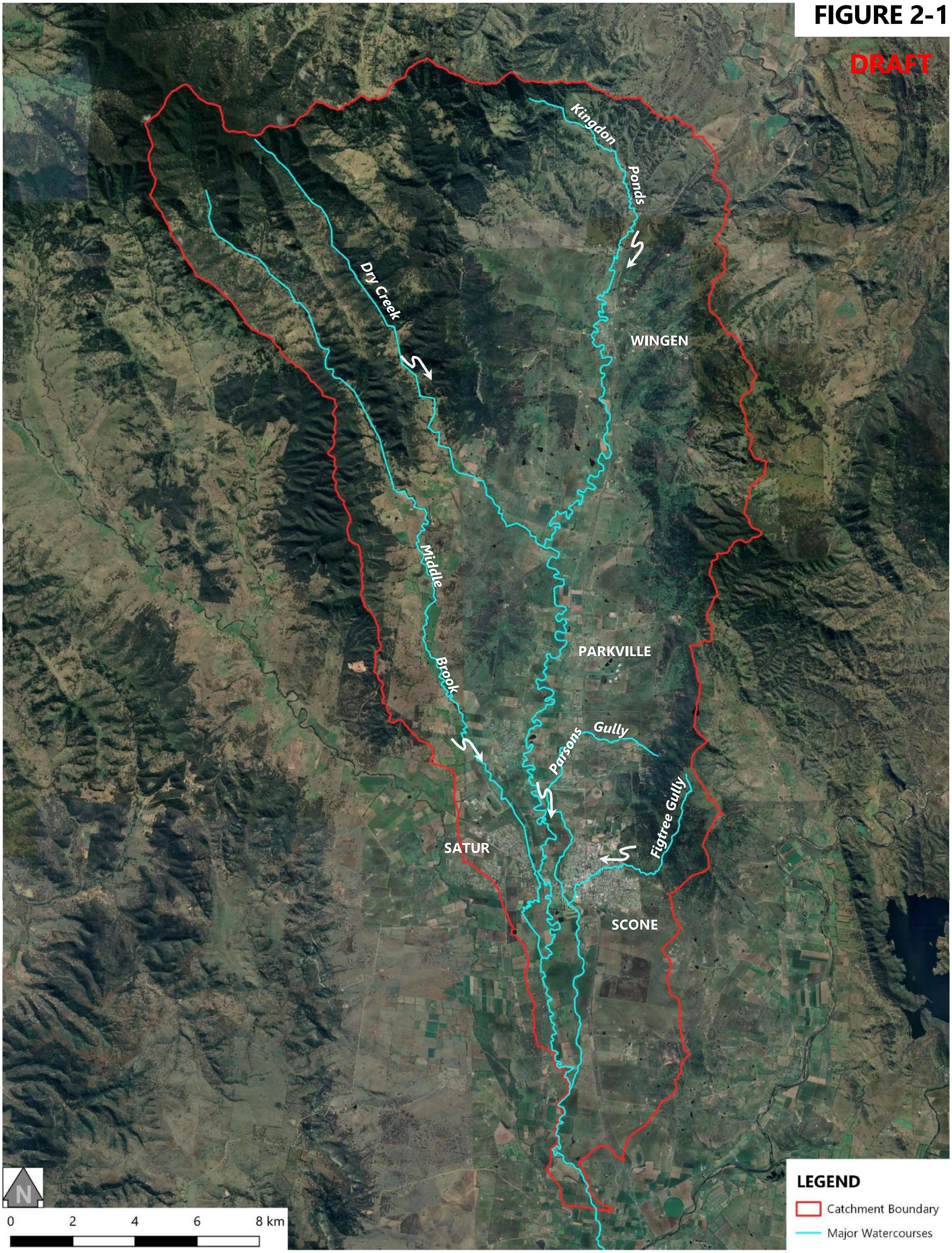
As noted previously, the upper catchments of the four key watercourses are mountainous areas to the north and east of Scone. Elevations in the upstream reaches of Parsons Gully and Figtree Gully exceed 450 mAHD, while elevations in the upstream reaches of Kingdon Ponds and Middle Brook exceed 800 mAHD. The gradient of the bed slopes in these areas are generally between 20% to 25%. Downstream of the mountains areas, the steep hilly terrain transitions into grassed floodplain areas between Wingen and Scone. The grassed floodplain areas are much flatter, with the gradient typically not exceeding 1%. Land elevations in this area range from 200 mAHD to 250 mAHD.

The terrain slopes from east to west through Scone. Elevations range from 200 mAHD at the western fringe of the town near Aberdeen Street to about 240 mAHD at the eastern fringe of town near Barton Street and Bhima Drive. At Satur, the land generally slopes from north-west to south-east.

Key features of the study area are shown in **Figure 2-1** and **Figure 2-2**, while the topography of the study catchment is shown in **Figure 2-3**.

FIGURE 2-1

DRAFT



UPPER HUNTER SHIRE COUNCIL

Prepared by:

worley consulting

STUDY AREA [CATCHMENT]

FIGURE 2-2

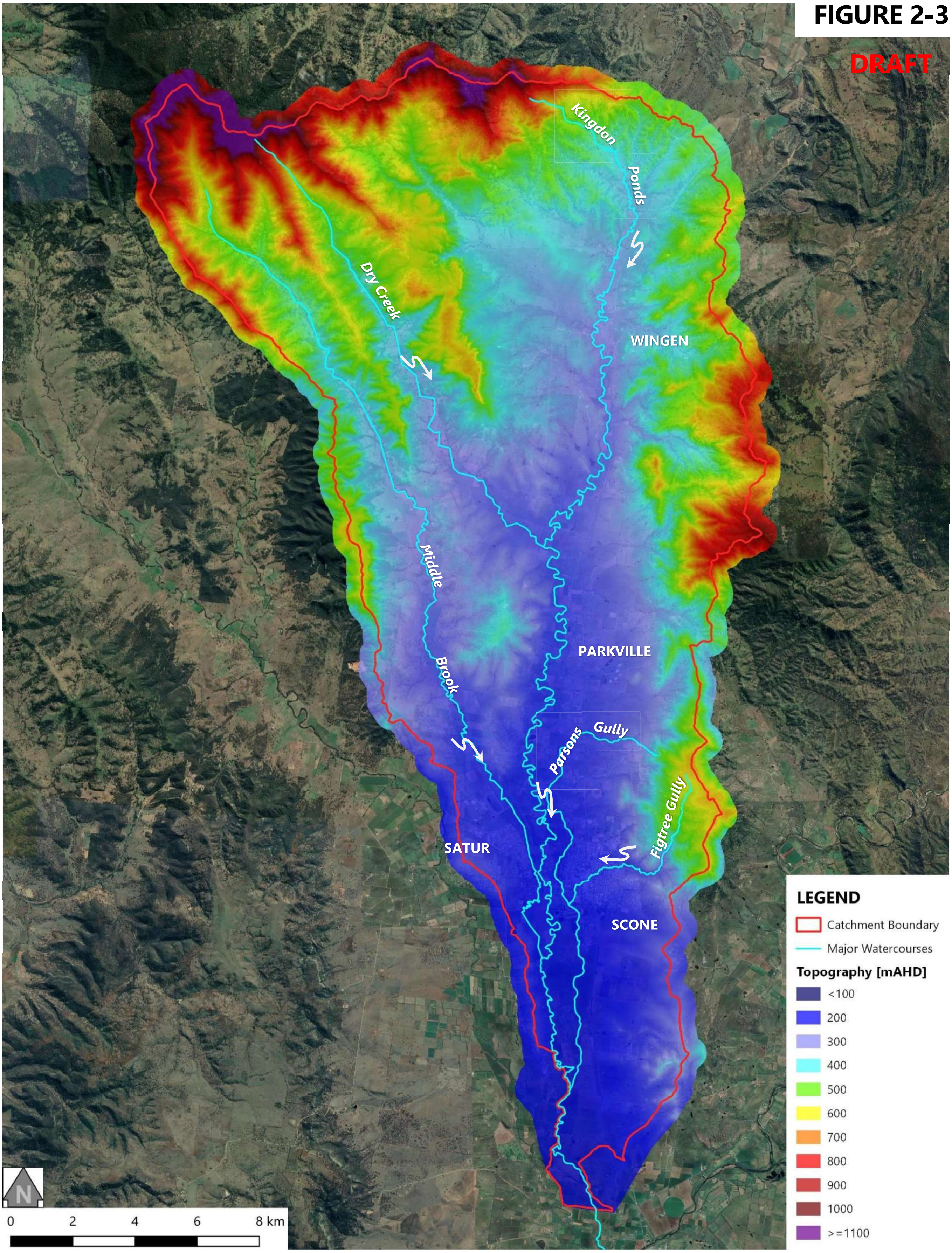
DRAFT

Prepared by:

STUDY AREA
[SCONE & SATUR]

FIGURE 2-3

DRAFT



UPPER HUNTER SHIRE COUNCIL

Prepared by: worley consulting

TOPOGRAPHY WITHIN THE STUDY CATCHMENT

2.3. The NSW Floodplain Risk Management Process

The NSW Government's *Flood Prone Land Policy* is directed towards providing solutions to existing flooding problems in developed areas and ensuring that new development is compatible with the existing flood hazard and does not create additional flooding problems in other areas. Policy and practice are defined in the *Floodplain Development Manual* (NSW Government, 2005).

Under the Policy, the management of flood liable land remains the responsibility of local government. The State Government provides financial and technical assistance to local government through its Floodplain Management Program which is administered by the Office of Environment and Heritage (OEH).

The NSW Floodplain Risk Management Process consists of a number of stages as defined in the *Floodplain Development Manual* and reproduced in **Figure 2-4**. The process is cyclical, and reviews may be triggered by various instances, for example the occurrence of significant flood events which provide additional data on flood behaviour, or the occurrence of significant changes to the catchment condition over time.

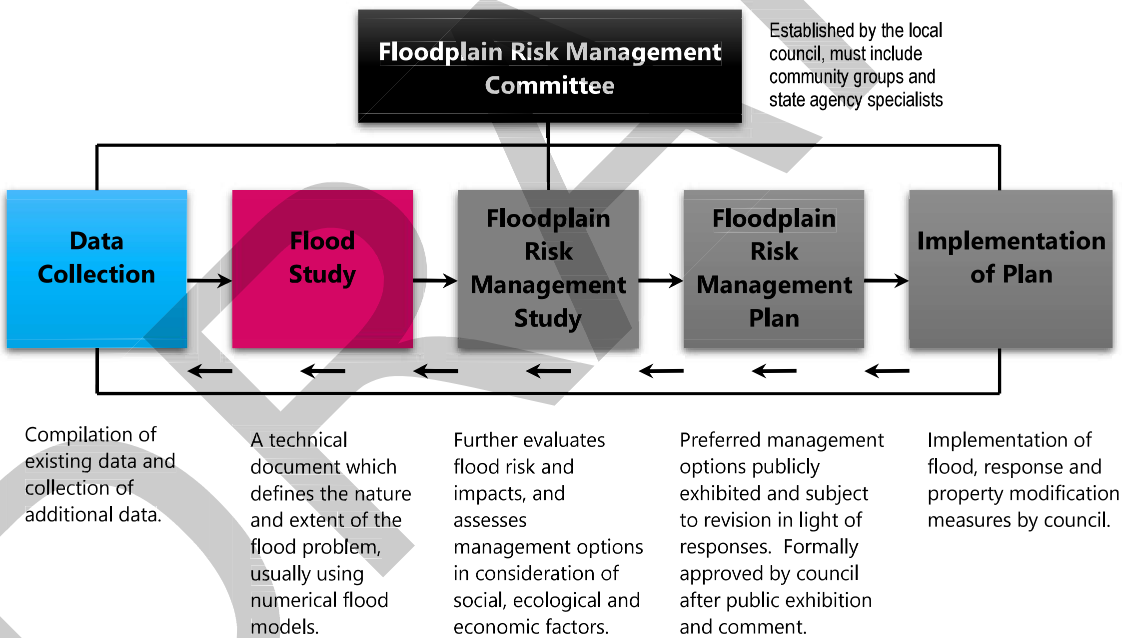


Figure 2-4 Stages of the NSW Floodplain Risk Management Process

In 2019, Upper Hunter Shire Council received support from the Department of Planning and Environment (DPE) to review and update the existing floodplain management study and plan for Scone, which was prepared by Bewsher Consulting in 1999.

An overview of previous studies completed in the study area and the triggers for the current review process are discussed in the following.

2.4. Previous Flood Investigations

A number of flood-related studies have previously been completed in the Scone catchment, including a series of studies in accordance with the NSW Floodplain Risk Management Process. Further information on each study is provided in the following.

2.4.1. Scone Flood Study (1996)

The Scone Flood Study prepared by the Department of Land & Water Conservation (DLWC) included the development of a RAFTS-XP hydrologic model and a 1D MIKE 11 hydraulic model. The flood models were used to assess the nature and extent of flooding along Middle Brook, Kingdon Ponds and Parsons Gully but did not address flooding along Figtree Gully.

The models were calibrated and validated against the January 1976 and February 1992 flood events. The report indicated that the model calibration results generally achieved a satisfactory match with recorded flood levels. Areas where notable differences were observed were attributed to a lack of reliable survey data as well as the 'radical meanders' along Kingdon Ponds, which were difficult to represent in the 1D hydraulic model.

The study involved the simulation of the 10, 20, 50, 100 and 200 year Average Recurrence Interval (ARI) floods, in addition to the Probable Maximum Flood (PMF).

2.4.2. Scone Floodplain Management Study and Plan (1999)

Following the completion of the 1996 Flood Study, Council engaged Bewsher Consulting to prepare the Scone Floodplain Management Study and Plan (the Scone FPMS & Plan). The objective of this study was to minimise the impact of flooding within the Middle Brook, Kingdon Ponds and Parsons Gully floodplains.

Notably, the Scone FPMS & Plan also included an assessment of flooding along Figtree Gully. A separate RAFTS-XP hydrologic model was developed for the Figtree Gully catchment, which adopted a different storage routing factor to the model developed for the 1996 Flood Study. A 1D HEC-RAS hydraulic model was also developed for this catchment.

The newly developed models indicated that the Figtree Gully system only had limited flow conveyance capacity. The models predicted that flows would overtop the channel downstream of Waverley Street in events as frequent as the 5 year ARI flood. Once the capacity of the channel is exceeded, floodwaters are expected to route overland to the south and west through several residential lots and along road reserves. Several properties along Kelly Street in the Scone CBD are also expected to be inundated.

Several mitigation options were recommended in the Floodplain Management Plan. The recommended options are summarised below.

Flood modifications options:

- Reconstruction of Figtree Gully to increase conveyance capacity;
- Removal of obstructions in the Figtree Gully channel;
- Introduction of on-site stormwater detention policies in the Figtree Gully catchment.

Property modification options:

- Raising of 10 houses in the Parsons Gully catchment;
- Flood-proofing of commercial properties in the Scone CBD;
- Improvement of existing building and development controls;
- Preparation of a vegetation management plan for each major waterway.

Response modification options:

- Issue of flood certificates to all property owners on a regular basis;
- Improvement of emergency planning and management;
- Increasing community education and flood awareness;
- Improvement of flood warning systems;
- Preparation of flood action plans for individual properties.

2.4.3. New England Highway Bypass at Scone - Flood Modelling Report (2017)

Road and Maritime Services (RMS) engaged GHD to undertake a detailed hydrologic and hydraulic assessment of flood behaviour in the vicinity of the preferred route of the proposed Scone Bypass alignment.

This assessment included the establishment of a new XP-RAFTS hydrologic model and a new TUFLOW hydraulic model, which were developed between 2015 and 2017. The models were used to analyse flood behaviour for existing conditions for the 10, 20, 100, 200, 500 and 2000 year ARI events as well as the PMF. The works and structures associated with the Scone Bypass were incorporated into a post-development version of the flood models, which was then used to establish flood behaviour for post-development conditions. The post-development flood results were then compared against the existing conditions flood results to analyse the predicted flood impacts associated with the Scone Bypass.

The TUFLOW hydraulic model was provided to Worley Consulting for review to assess its suitability for adoption in the current flood study. Further details are provided in **Section 3.2**.

2.4.4. Scone CBD Revitalisation Project – Flood Impact Assessment (2021)

Council is undertaking the Scone CBD Revitalisation Project which involves major landscaping works and beautification upgrades to Kelly Street between Kingdon Street and Susan Street. The proposed works include cut and fill earthworks as well as realignment of the kerb along Kelly Street. The existing stormwater network in the vicinity of Kelly Street is also to be upgraded as part of this project.

Worley Consulting (*then Advisian*) was engaged by Council to undertake a Flood Impact Assessment (FIA) aimed at quantifying the benefits of the proposed road and stormwater upgrade in reducing flood affectation of commercial properties fronting Kelly Street. The FIA was undertaken concurrently with the updated Scone Flood Study. The FIA adopted the Figtree Gully sections of the WBNM and TUFLOW flood models which had been developed for the updated Scone Flood Study.

A key component of the FIA comprised the verification of the WBNM runoff lag factor 'C'. A 'C' factor of 0.9 was determined as part of the calibration process in the updated Scone Flood Study (refer

Section 5 for further details). However, this calibration process was completed based on consideration of streamflow gauges located outside of the Figtree Gully catchment.

Accordingly, the February 1992 historic event was investigated to verify an appropriate value of 'C' for the Figtree Gully catchment. Following this verification process, a 'C' factor of 1.3 was recommended for adoption for the Figtree Gully catchment. Further details of this model verification process are provided in **Appendix A**.

2.5. The Need for the Update of the Scone Flood Study

The current Scone Flood Study was triggered in response to a variety of factors. These factors are listed below.

- Changes to the catchment since the 1996 Flood Study and 1999 Floodplain Management Study and Plan, such as the Scone Bypass.
- Availability of updated Airborne Light Detection and Ranging (LiDAR) topographic survey of the study area captured in 2017.
- Additional ground and structural survey undertaken during the Scone CBD Revitalisation Project and as part of the data collection process for this study.
- Advancements in flood modelling capability
  - The *Scone Flood Study* (*DLWC, 1996*) and *Scone Floodplain Management Study and Plan* (*Bewsher Consulting, 1999)* adopted one-dimensional (1D) hydraulic models. In such 1D models the floodplain is schematised into a series of user defined stream reaches and cross-sections. Flows may occur in only one pre-defined direction along a stream, and flood levels are constant across a cross-section. As a result, flood conditions along some tributaries and overland flowpaths were not defined, and complex flooding patterns may not have been captured in some areas.
  - The current study has adopted a two-dimensional (2D) hydraulic model which provides a continuous representation of the entire floodplain surface and allows fine-scale spatial variation in flood level, flow direction and velocity. Such models are far superior to 1D models in their representation of complex flow patterns in urban areas including their ability to resolve flow diversions and alternative flow paths.
- Release of updated guideline and policy documents
  - Issue of *Australian Rainfall and Runoff: A Guide to Flood Estimation 2019* (*ARR 2019*)
  - Release of new planning and policy documents such as *Upper Hunter Development Control Plan* (2015).
- The need to investigate future flood risk including the potential impacts of climate change.

2.6. Relevant Manuals and Guidelines

2.6.1. Floodplain Development Manual, 2005

The *Floodplain Development Manual* 2005 (the Manual) incorporates the NSW *Flood Prone Land Policy* and guides its implementation in the floodplain risk management process. It aims to reduce the impacts of flooding and flood liability on individual owners and occupiers of flood prone property and to reduce private and public losses resulting from floods.

The Manual outlines a merit-based framework to assist with floodplain risk management. It confirms that responsibility for management of flood risk remains with local government and provides guidance for councils in the development and implementation of local floodplain risk management plans.

A series of floodplain risk management guidelines were developed by the former OEH (*now DPE*) to complement the *Floodplain Development Manual*, providing additional technical information to councils and consultants to support the preparation and implementation of floodplain risk management plans. Guidelines referenced in the preparation of this study include:

- Floodway definition
- Flood emergency response classification of communities
- Residential flood damage and supporting calculation spreadsheet
- SES requirements from floodplain risk management process.

2.6.2. Flood Risk Management Manual, 2023

The *Flood Risk Management Manual* (DPE 2023) updates the Floodplain Development Manual (2005) and several of the existing technical guides. It considers lessons learnt from floods and the application of the flood risk management process and manual since 2005.

The *Flood Risk Management Manual* (DPE 2023) was released in draft form during the course of undertaking this flood study and was finalised during its latter stages. While effort was made to consider the new manual in the preparation of the flood study, it is possible that some implications of its introduction have not been fully addressed.

Associated guides referenced in the preparation of this study include:

- FB01 Understanding and Managing Flood Risk
- FB02 Flood Function
- FB03 Flood Hazard
- MM01 Flood Risk Management Measures
- EM01 Support for Emergency Management Planning.

2.6.3. Australian Rainfall and Runoff, 2019

Australian Rainfall and Runoff: A Guide to Flood Estimation 2019 (*ARR 2019*) was issued for use by practitioners in draft form in November 2016 and was finalised in May 2019. It provides an updated national guideline document, data and software suite for the estimation of design flood characteristics in Australia.

The guidelines update previous editions of ARR in light of recent advances in knowledge regarding flood processes, the increased computational capacity available to hydrologists and flood engineers, expanding knowledge and application of hydro-informatics, improved information about climate change and the use of more detailed hydrological methods.

The guidelines also incorporate new Intensity-Frequency-Duration (IFD) design rainfall estimates developed by the Bureau of Meteorology (BoM), using 30 years of additional observations from over 10,000 rainfall gauging stations and improved statistical analysis techniques.

2.6.4. Australian Disaster Resilience Handbook 7, 2017

Australian Disaster Resilience Handbook 7 Managing the Floodplain: A Guide to Best Practice in Flood Risk Management in Australia (AIDR 2017) provides guidance on best practice principles as presently understood in Australia. It provides information on the underlying principles that need to be considered when managing flood risk and formulating floodplain management plans and how to apply it, with the aim of promoting effective, equitable and sustainable land use across Australia's floodplains. A number of supporting documents are provided in conjunction with Handbook 7 and have been referenced in the preparation of this study.

3. Data Collection and Review

3.1. Stormwater and Drainage Asset Data

Stormwater asset data was provided by Council in the form of a GIS layer and a spreadsheet database:

- "Stormwater_UHSC_2019.kml"
  - GIS layer containing linework only (i.e., no associated survey details)
- "UHSC_Scone_Stormwater_Bridges_Major_Culverts_Data.xlsx"
  - Some details on 1997 stormwater pits and pipes (e.g., pipe dimensions and pit depth).

This data was used as the basis for inclusion of the pit and pipe drainage system at Scone and Satur in hydraulic modelling. However, the required data was missing or ambiguous for a significant number of the stormwater assets in the Excel database. In these cases, a number of logical assumptions were adopted to complete the data set and include in the drainage system in the hydraulic model.

- The minimum LiDAR ground level within a radius of 5 m was adopted where headwall invert levels were not provided.
- Where pit invert levels were not provided, they were estimated by subtracting a minimum depth of cover of 0.5 m and culvert height from the ground level.
- Where pipe dimensions were not provided, they were estimated from the nearest pipe with available dimension data.

The Excel database also included data on 144 major culverts and bridges in the Upper Hunter Shire LGA. However, most of these structures are located outside of the study area. Some details were available for the hydraulic structures within the study area, such as bridge deck width, culvert type and number of barrels. Logical assumptions were also required where the necessary data was not provided.

3.2. Scone Bypass Flood Model

The Scone Bypass flood assessment was undertaken by GHD between 2015 and 2017 to evaluate the impact of the proposed bypass on existing flood characteristics at Scone (refer **Section 2.4.3**). As noted previously, this involved the development of a TUFLOW hydraulic model of the floodplain in the vicinity of the bypass.

The TUFLOW model files and results were provided by Council and reviewed as part of the data collection process. Following a detailed review of the model, a number of limitations was identified and the model was not adopted as the base hydraulic model for this current study. For example, the model only covers the Figtree Gully catchment up to Park Street, which would not allow flood conditions to be defined for significant portions of the Scone township.

However, the topographic representation of the Scone Bypass and its associated cross-drainage structures were found to be of high quality. Accordingly, these relevant components were extracted from the Scone Bypass TUFLOW flood model for adoption into the hydraulic model for this current study.

3.3. Site Visit

A site inspection was undertaken by Worley Consulting in August 2020, focusing on key drainage structures in the vicinity of Scone. This was completed as a ground-truthing exercise to verify the data provided in Council's stormwater asset database and the details of key cross-drainage structures in the Scone Bypass TUFLOW model. A selection of the photos taken during the site visit are shown in Error! Reference source not found. to **Figure 3-3**.

Figure 3-1 Photo of the Figtree Gully box culvert beneath Kelly Street

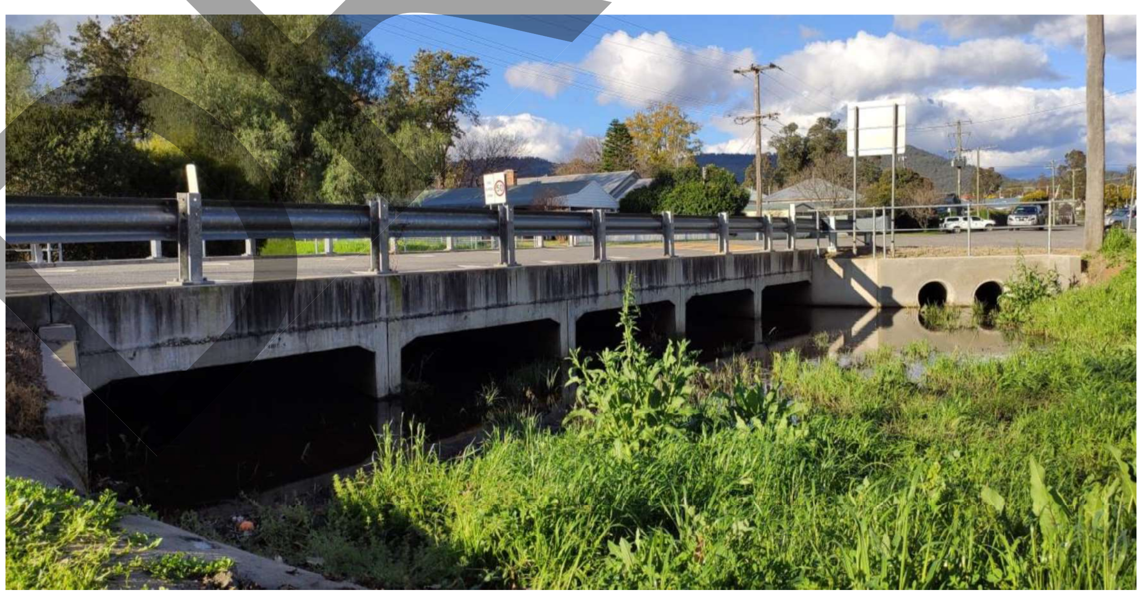


Figure 3-2 Photo of the Figtree Gully culverts beneath Kingdon Street

Figure 3-3 Photo of the Parsons Gully culverts beneath Liverpool Street

3.4. Topographic Data

The following topographic datasets were collected, reviewed and adopted to establish a Digital Elevation Model (DEM) for the study catchment:

- NSW Spatial Services LiDAR survey of the Muswellbrook region captured in November 2017 (2-metre grid) with a reported accuracy of 0.3 m in the vertical and 0.8 m in the horizontal; and,
- NSW Spatial Services LiDAR survey of the Murrurundi region captured in November 2011 (5-metre grid) with a reported accuracy of 0.9 m in the vertical and 1.25 m in the horizontal.
- 12D model files defining the post-development landform for the Scone Bypass, extracted from the TUFLOW model developed for the Scone Bypass flood assessment completed by GHD in 2017.

The NSW Spatial Services LiDAR topographic data was sourced from the online ELVIS system by Geosciences Australia. The Muswellbrook LiDAR data covers the southern half of the study catchment from Aberdeen to Parkville, including the Scone township and the satellite suburb of Satur. The Murrurundi LiDAR data extends from Parkville in the south to Murrurundi in the north.

3.5. Additional Survey

A review of the available information and data described in **Section 3.1** to **Section 3.4** identified inconsistencies or data gaps at a number of critical hydraulic structures in the study areas. These key culverts / bridges would have a significant influence on flood behaviour and accordingly, it is important that these structures be reliably represented in the flood model.

Council engaged MM Hyndes Bailey in March 2022 to undertake a detailed survey of the following structures:

- Liverpool Street bridge over Middle Brook
- Liverpool Street bridge over Kingdon Ponds
- Parsons Gully culverts beneath Liverpool Street
- Culverts beneath Gundy Road near the Barton Street intersection
- Two Mile Gully culverts beneath the New England Highway
- Parsons Gully culverts beneath the New England Highway
- Turanville Road bridge over Kingdon Ponds
- Parsons Gully culverts beneath Turanville Road.

Additionally, a survey of the stormwater network pits and pipes was completed as part of the Scone CBD Revitalisation Project in September 2020. This comprised the collection of details such as pipe dimensions and pit invert levels for the stormwater network system near to and east of the Scone CBD.

3.6. Hydrometric and Historic Flood Data

A thorough search of available databases was undertaken to identify hydrometric data stations within or near the catchments of Middle Brook, Kingdon Ponds, Parsons Gully and Figtree Gully (the Scone catchment). The search established that there was a considerably greater amount of flood data available for the Scone catchment from 2003 onwards.

3.6.1. Stream Level Data

Available stream level records for the Scone catchment were obtained from the Bureau of Meteorology (BoM) and Water NSW, comprising data from the following stations:

- 561099 Dry Creek (BoM)
- 561100 Wingen (BoM)
- 561101 Cressfield (BoM)
- 61360 Scone (Kingdon Ponds) (BoM)
- 210093 Kingdon Ponds near Parkville (Water NSW).

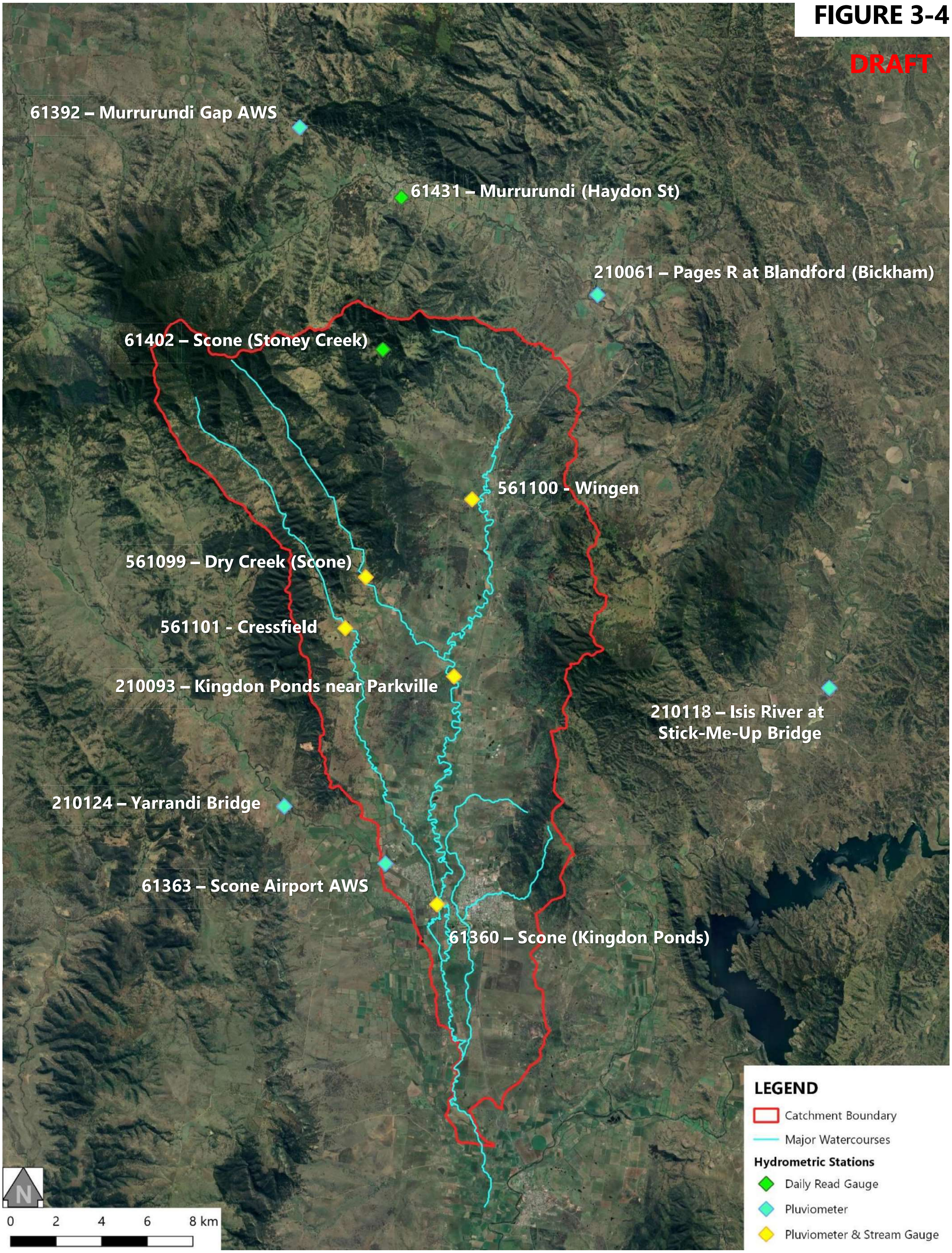
The locations of these stream level gauges are shown in **Figure 3-4**.

3.6.2. Rainfall Data

Rainfall data was sought from stations within and surrounding Scone catchment. A particular focus was placed on obtaining data from pluviometers (*gauges that record continuous sub-daily rainfall*) in order to be able to resolve the temporal pattern of rainfall across the catchment during past flood events.

Rainfall stations from which data was used in the study are shown in **Figure 3-4**.

FIGURE 3-4



UPPER HUNTER SHIRE COUNCIL

Prepared by: worley consulting

HYDROMETRIC STATIONS ADOPTED FOR MODEL CALIBRATION / VALIDATION

4. Flood Model Development

4.1. Modelling Approach

Numerical computer models have been adopted as the primary means of investigating flood behaviour for the Scone catchment. When used carefully, modern computer models allow simulation of flood behaviour over large areas in a cost efficient and reliable manner.

For this study, the WBNM hydrologic and TUFLOW 2D/1D hydraulic modelling software packages were selected. The hydrologic model simulates the catchment rainfall-runoff processes, with resulting flow hydrographs input to the hydraulic model. The hydraulic model simulates the physical behaviour of the flow as it passes through the catchment, producing information on flood levels, flood extents and flow velocities.

The WBNM and TUFLOW software were determined to be suitable tools for replicating the complex 2D nature of flooding in the study catchment based on consideration of the following.

- WBNM hydrologic modelling software:
  - WBNM is very robust and has been validated against numerous catchments in NSW.
- TUFLOW hydraulic modelling software:
  - Allows accurate representation of catchment topography and bathymetry to be developed in 2D from various sources (e.g., a combination of LiDAR and detailed survey);
  - Allows integrated investigation and interaction of overland, mainstream, tidal and ocean driven components of flooding;
  - Solves the full 2D surface water equations; and
  - Produces high quality, GIS compatible flood mapping outputs.

4.2. Hydrologic Model Development

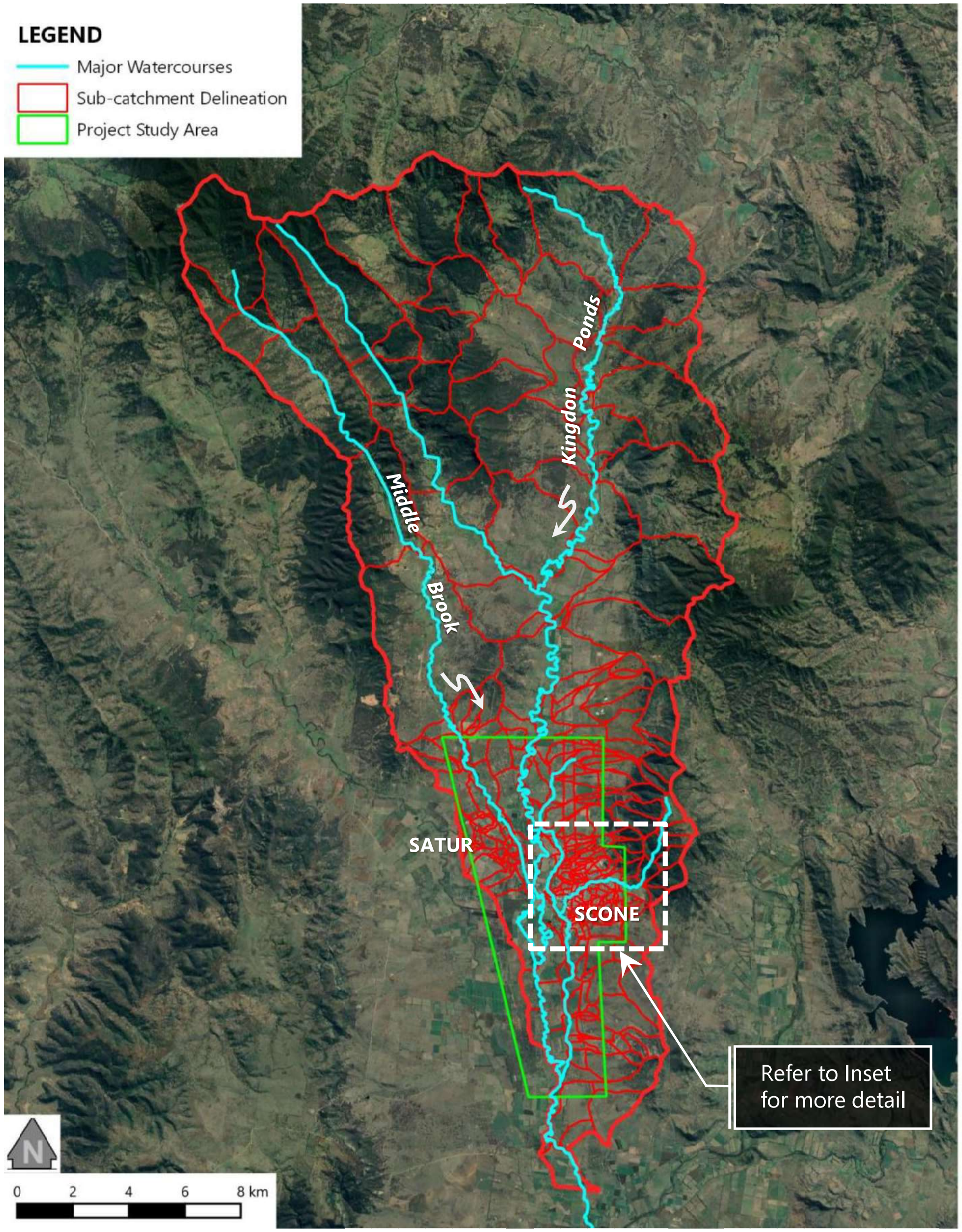
4.2.1. Model Layout

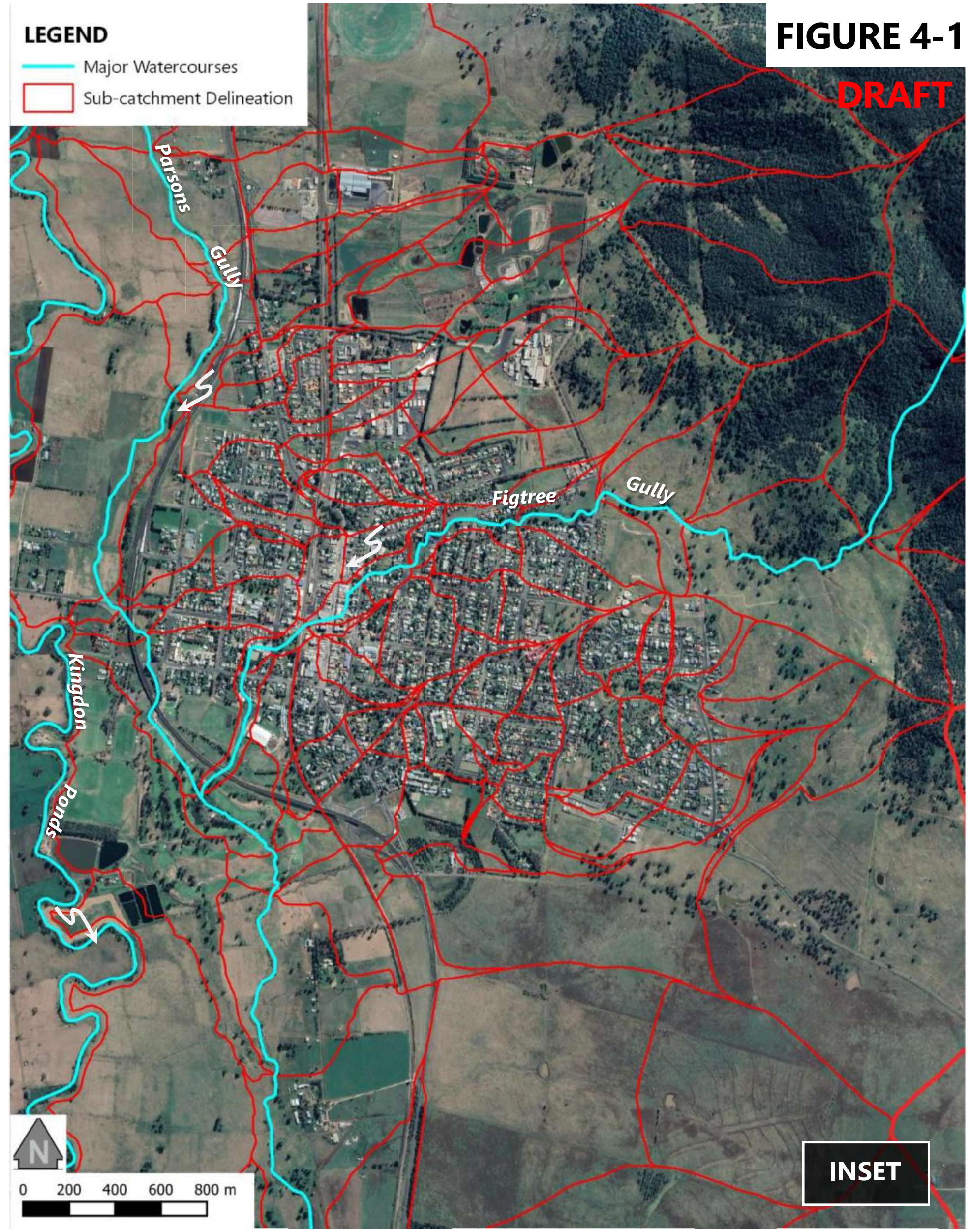
The WBNM hydrologic modelling software was used to simulate rainfall-runoff processes to determine flow hydrographs for input to the hydraulic model. The flow hydrographs were determined on a fine spatial scale to ensure that flooding of major watercourses as well as overland flow paths could be properly resolved in the hydraulic model.

The extent of the catchments of Middle Brook, Kingdon Ponds, Parsons Gully and Figtree Gully was determined from topographic data using the CatchmentSIM hydrologic and terrain analysis software. The catchments were further delineated into 344 sub-catchments based on consideration of catchment topography, flood flow paths (as identified through initial direct rainfall hydraulic modelling) and the location of major culverts, bridges and stream flow gauges. While many sub-catchments are either larger or smaller, the delineation generally aimed to produce sub-catchments in the order of 2 to 10 ha in the developed sections of the study area and 200 to 500 ha in the undeveloped areas. The adopted WBNM hydrologic model sub-catchment delineation is presented in **Figure 4-1**. The sub-catchment delineation and linkage form the foundation of the WBNM hydrologic model structure.

FIGURE 4-1

DRAFT





UPPER HUNTER SHIRE COUNCIL

Prepared by: worley consulting

WBNM HYDROLOGIC MODEL SUB-CATCHMENT DELINEATION

4.2.2. Runoff Lag and Stream Routing Parameters

The primary parameters required by the WBNM model are a runoff lag factor 'C', and a stream routing lag factor 'F'.

The runoff lag factor 'C' controls the timing of locally generated runoff from each model sub-catchment. A low C value represents a rapid runoff response, while a high value represents a slow runoff response. WBNM documentation recommends runoff lag parameter values of between 1.3 and 1.8, with a value of close to 1.6 generally appropriate. A separate lag factor is applied to impervious areas with a value of 0.1 recommended.

The stream routing lag factor 'F' determines the time it takes for flows to travel along streams. WBNM documentation recommends a default stream lag factor of 1.0 to represent natural streams. Lower values can be adopted if the stream has undergone modifications such as clearing, straightening, or concrete lining. Conversely, a higher value could be adopted to represent streams which are overgrown or streams which have a high degree of meandering.

Adopted parameters were developed through the model calibration and verification process (refer **Section 5**). The final values are presented in **Table 4-1**.

Table 4-1 Adopted WBNM runoff lag and stream routing parameters

WBNM Model Parameter	Parameter Value
Runoff lag factor 'C'	0.9 (except C = 1.3 in Figtree Gully catchment)
Impervious runoff lag factor 'C'	0.1
Stream routing factor 'F'	Variable (0.5 to 6.0)

4.2.3. Hydrologic Model Stream Routing

The definition of flood levels and depths, which are the primary objective of this study, have been determined by applying 'local runoff' hydrographs from each sub-catchment of the WBNM model to the TUFLOW hydraulic model, which then computes the routing processes according to the detailed geometry of the watercourses and floodplains.

Stream routing within the WBNM hydrologic model is not therefore, explicitly required to define flood behaviour, but is useful to the study for other purposes as follows.

- For the assessment of critical storm durations and rainfall temporal patterns at key locations of interest, given the large number of storms required to be tested under ARR 2019, whereby the WBNM model can be used to complete these simulations much faster than the TUFLOW hydraulic model.
- The WBNM model was also used undertake particular sensitivity testing of hydrologic modelling parameters such as rainfall losses.

4.2.4. Catchment Imperviousness

The degree of imperviousness of a catchment influences both the quantity and timing of runoff generated by a rainfall event.

The effective impervious percentage of each sub-catchment of the WBNM model was determined through analysis of the different types of land use in the Scone catchment, based on the most recent aerial imagery available from Google Satellite. It is noted that different effective impervious percentages were assigned to the different towns in the study area based on the lot density.

The effective percentage impervious was assigned to each land use type with reference to guidance presented in Australian Rainfall and Runoff 2019 (ARR 2019) and is presented in **Table 4-2**.

Table 4-2 Effective Percentage Impervious for Different Land Uses

Land Use / Town	Effective Percentage Impervious
Scone	35%
Wingen / Parkville	20%
Middle Brook	15%
Satur	30%
Rural Areas	2%
Dams / Ponds	100%
Industrial Areas	80%
Major Roads / Airstrips	100%

4.2.5. Rainfall Loss Rates

Rainfall losses refers to precipitation that does not contribute to direct runoff. During a storm, such losses occur primarily due to the processes of interception by vegetation and infiltration into the soil. The initial loss-continuing loss (IL-CL) approach is typically used in Australia to account for losses in the rainfall-runoff process and has been adopted in this study.

The initial and continuing loss values adopted in hydrologic simulations were determined following the calibration and verification process and comparison against previous studies in nearby catchments (refer **Sections 6.3.4**).

4.3. Hydraulic Model Development

4.3.1. 2D Model Domain and Terrain

The TUFLOW hydraulic modelling software was used to develop a two-dimensional flood model of the study area. The 2D TUFLOW hydraulic model domain covers an area of 81.6 km^2 including the following key features of the floodplain:

- the urban areas of the township of Scone;
- the urban areas of the township of Satur;
- Middle Brook, Kingdon Ponds, Parsons Gully and Figtree Gully in the vicinity of Scone and Satur;
- the 210093 and 61360 stream flow gauges; and
- the new Scone Bypass development.

A model grid size of 4 m was adopted to ensure suitable resolution of flood characteristics in the study area, resulting in over 5 million computational grid cells. Each square grid cell contains information on ground surface elevation, hydraulic roughness and other parameters as required; e.g., cell blockage and energy losses to represent the hydraulic effects of culverts and bridges. The ground surface elevation is sampled at the centre, mid-sides and corners of each cell from a specified Digital Elevation Model (DEM). For a 4 m grid this results in DEM elevations being sampled at 2 m centres. The hydraulic model extent is shown in **Figure 4-2**.

The 2D TUFLOW model terrain was constructed from the three data sources described in Section 3.4. The model terrain is shown in **Figure 4-3**.

4.3.2. Boundary Conditions

The TUFLOW hydraulic model boundary conditions consist of the following:

- 'Surface area' application of flow hydrographs from each hydrologic model sub-catchment (refer **Figure 4-1**) to the 2D hydraulic model domain. 'Total' flow hydrographs were applied at the upstream extents of the model, while 'local' inflow hydrographs were applied for sub-catchments falling within the TUFLOW model domain.
- A normal-depth boundary at the southern extent of the model that allows runoff to flow out of the model (refer **Figure 4-2**). A gradient of 0.5% was adopted based on the topography in the vicinity of the downstream model boundary.

4.3.3. Hydraulic Roughness

Hydraulic roughness coefficients (Manning's 'n') are used to represent the resistance to flow of different surface materials. Hydraulic roughness has a major influence on flow behaviour and is one of the primary parameters that may be altered to achieve calibration of hydraulic models.

Spatial variation in hydraulic roughness is represented in TUFLOW by delineating the catchment into zones of similar hydraulic properties. The hydraulic roughness zones adopted in this study have been delineated based on consideration of aerial photography, cadastral data and site observations. Manning's 'n' roughness values assigned to each zone were determined based on site observations and previous experience, with reference to values recommended in the literature (e.g. Chow 1959). As resistance to flow due to surface and form roughness varies with depth (as noted by Chow 1959 and ARR 1987), variable depth-dependent hydraulic roughness values have been adopted.

Manning's 'n' roughness coefficients applied in the TUFLOW model are listed in **Table 4-3**, with the delineation of hydraulic roughness zones shown in **Figure 4-4**. Below 'Depth 1' the first Manning's 'n' value is applied, while above 'Depth 2' the second Manning's 'n' value is applied. At depths between 'Depth 1' and 'Depth 2' Manning's values are determined by linear interpolation.

Table 4-3 Adopted Manning's 'n' Hydraulic Roughness Coefficients

Material	Depth 1 (m)	Manning's 'n' Value 1	Depth 2 (m)	Manning's 'n' Value 2
Watercourses	0.5	0.10	2.0	0.04
Buildings	-	3.00	-	-

Material	Depth 1 (m)	Manning's 'n' Value 1	Depth 2 (m)	Manning's 'n' Value 2
High Density Residential	0.3	0.20	1.5	0.10
Low-Med Density Residential	0.2	0.10	0.6	0.06
Industrial/Commercial Yard	0.1	0.10	0.3	0.06
Open Space	0.1	0.06	0.3	0.04
Vegetation – Medium Density	0.15	0.16	0.5	0.08
Road Corridor	0.05	0.05	0.10	0.03
Rail Corridor	0.1	0.16	0.3	0.08

4.3.4. Bridges

The influence of bridges on flood behaviour has been represented in 2D using 'layered flow constrictions' which assign flow area reductions and energy losses that simulate the hydraulic effects of bridge piers, the bridge deck, railings and parapets.

The geometry of the bridges including pier arrangement, span, deck thickness, deck level and the detail of the handrails were based on the outcomes of the March 2022 survey, photos taken during Worley Consulting's site visit or estimated from Google Street View. Form losses for these components of the bridge structures were estimated using procedures detailed in the publication titled, Waterway Design (*AustRoads, 1994*). The locations of modelled bridges are shown in **Figure 4-5**.

4.3.5. Culverts and Stormwater Drainage System

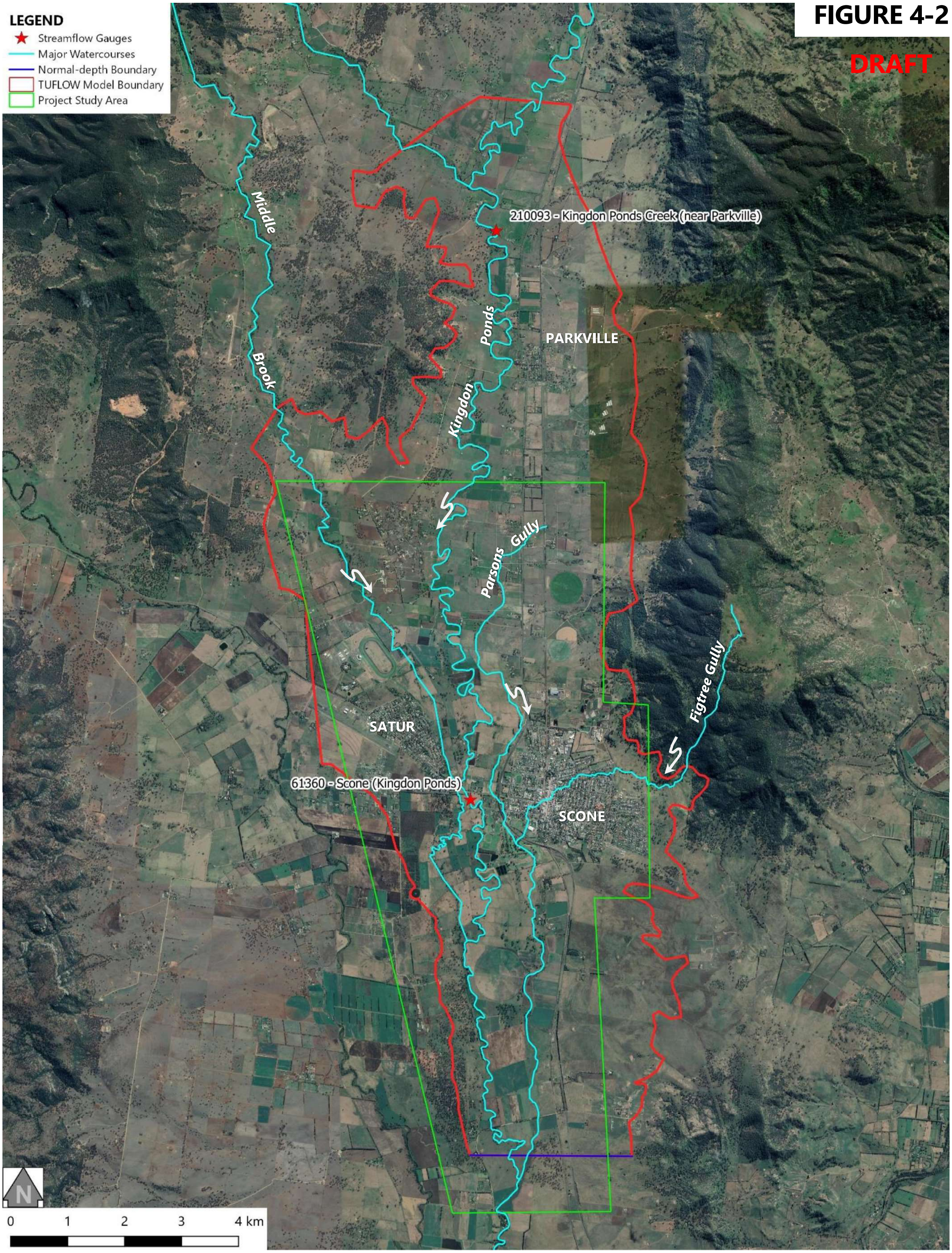
Culverts were represented in the TUFLOW model using 1D elements which are dynamically linked to the 2D surface grid to allow the transfer of flows. The details of the existing stormwater network were compiled from Council's stormwater asset Excel database. This was supplemented by data collected during a survey carried out in September 2020 as well as information provided in Council's stormwater asset pit and pipe GIS layers.

In some cases, not all information necessary for the representation of stormwater pits and pipes in the TUFLOW model was included in the GIS layers (e.g., invert level). A number of logical assumptions were required to complete the data set (refer **Section 3.1**)

Kerb inlet pit flow capture was modelled using in-built TUFLOW weir and orifice equations based on the inlet dimensions. Field pit flow capture was based on capture curves developed using equations specified in the Queensland Urban Drainage Manual (Department of Natural Resources and Water, 2007). Hydraulic losses were represented using TUFLOW's default Engelund approach and recommended entry and exit loss parameter values.

The extent of the culverts included in the TUFLOW model is shown in **Figure 4-5**.

DRAFT



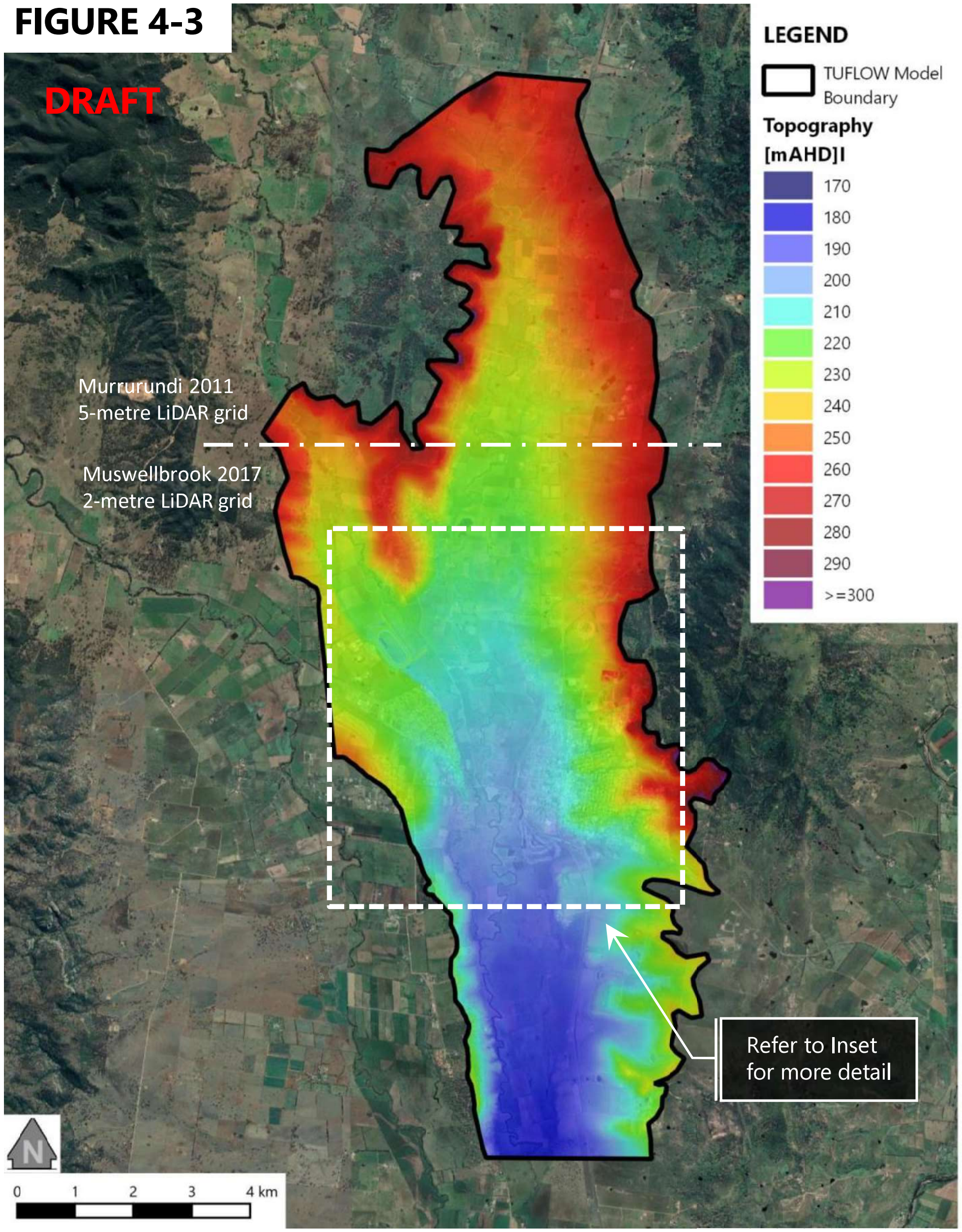
UPPER HUNTER SHIRE COUNCIL

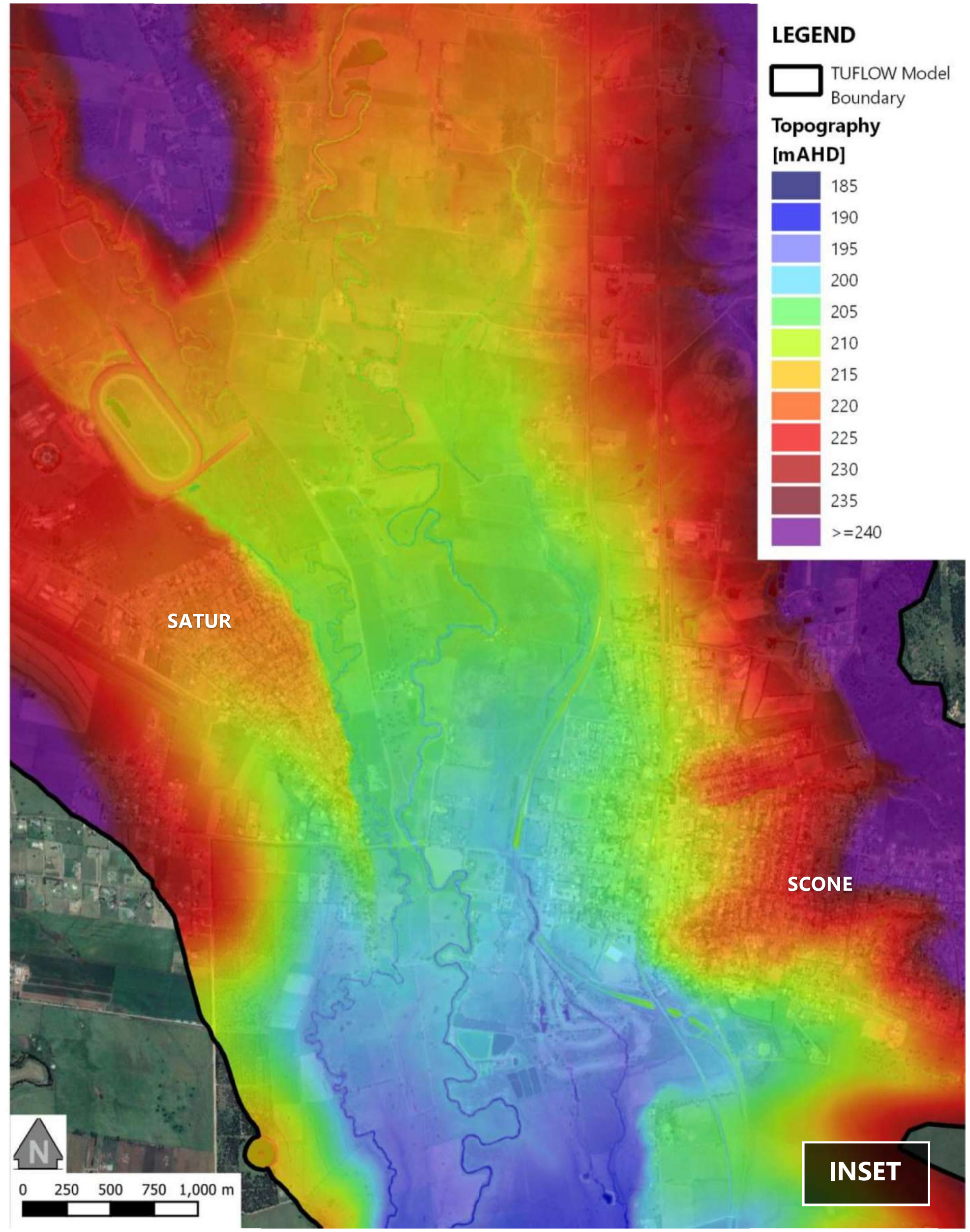
Prepared by:

worley consulting

TUFLOW MODEL DOMAIN

FIGURE 4-3



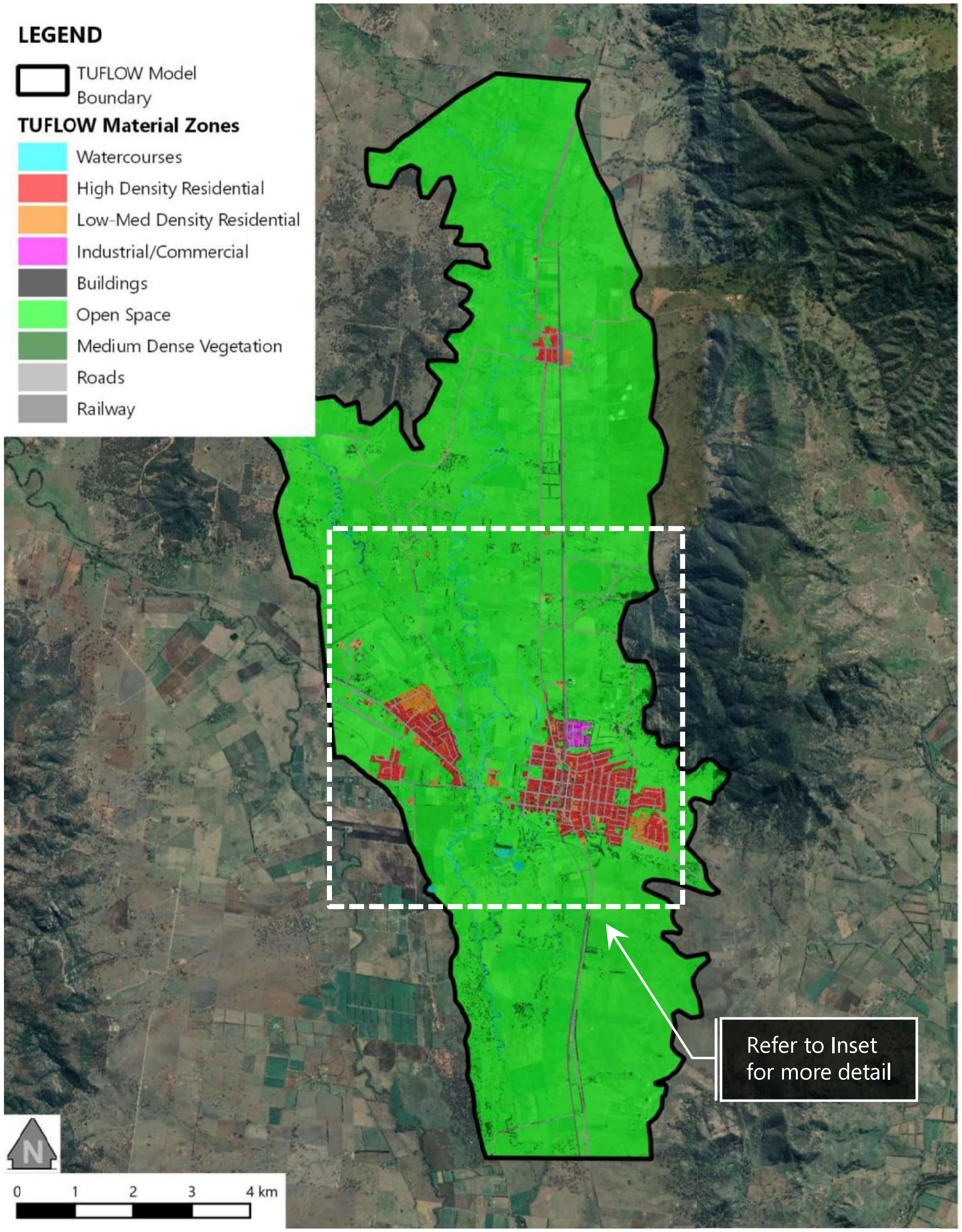


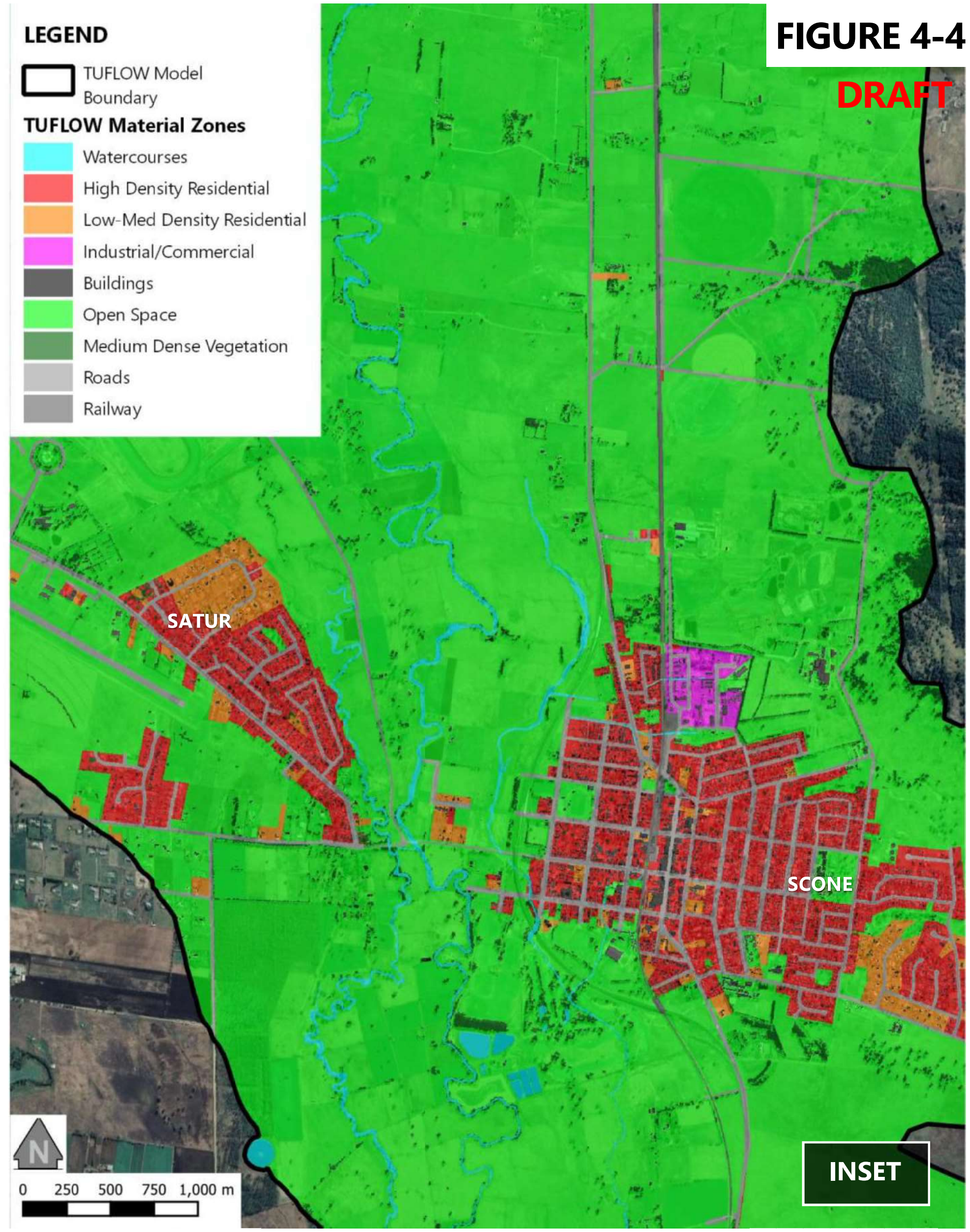
Prepared by: worley consulting

UPPER HUNTER SHIRE COUNCIL

TUFLOW MODEL TOPOGRAPHY

FIGURE 4-4





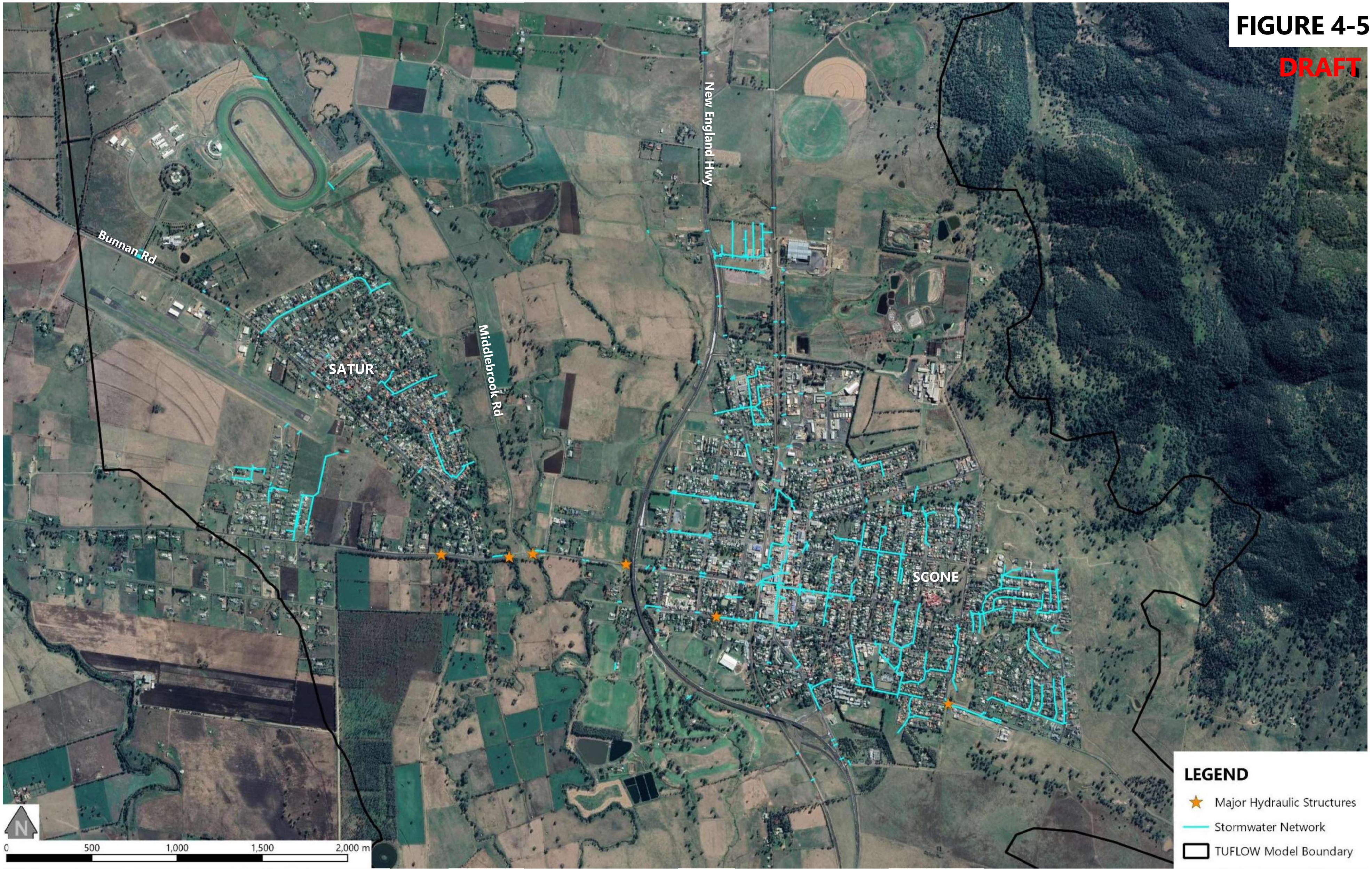
Prepared by: worley consulting

UPPER HUNTER SHIRE COUNCIL

TUFLOW MODEL HYDRAULIC ROUGHNESS DELINEATION

FIGURE 4-5

DRAFT



Prepared by:

LOCATION OF HYDRAULIC STRUCTURES INCLUDED IN THE TUFLOW MODEL

5. Model Calibration and Verification

5.1. Overview of Model Calibration and Verification

Model calibration and verification is an essential step in the flood modelling process. Confirmation that the models can reproduce observations and measurements from historical flood events is required to demonstrate their ability to reliably simulate expected flood behaviour in the study area. The approach in the current study was to undertake model calibration and verification to recorded data from flood events which occurred in November 2021 and December 2007.

The results provide confidence in the ability of the developed WBNM hydrologic and TUFLOW hydraulic models to realistically simulate observed flood behaviour across the study area. Comparisons of model results to recorded or observed water levels for multiple events have shown that the models are able to adequately reproduce the timing and extent of historical flood events.

5.2. Selection of Model Calibration and Verification Events

The suitability of historical flood events for use in model calibration and validation is generally dependent on the availability, completeness and quality of recorded rainfall, flood level and stream flow data. Accordingly, Worley Consulting contacted representatives from the Bureau of Meteorology to clarify the availability and amount of hydrometric data that could be purchased for the Scone catchment, in addition to the freely available data already downloaded at the commencement of the project. Through this process, it was established that there was a considerably greater amount of flood data available for the Scone catchment from 2003 onwards.

The November 2021 flood event resulted in the highest gauged levels for the period between 2003 and the present day. Considerable flood data is available for this event including rainfall records from various pluviometers as well as streamflow records along Kingdon Ponds near Parkville (gauge no. 210093) as well as near Scone just downstream of Liverpool St (gauge no. 61360). Additionally, there is drone footage available which shows the extent of flooding near the peak of the event. Accordingly, the November 2021 flood was adopted as the primary model calibration event.

The December 2007 flood event was chosen as the model verification event. This event represents one of the highest recorded flood levels at the 210093 gauge during the period of greater hydrometric station availability for the Scone catchment from 2003 onwards. Importantly, we found that there were five gauges with available stream flow / stream depth data for the December 2007 event, which would enable a more detailed verification of the WBNM hydrologic model.

5.3. Flood Frequency Analysis

A flood frequency analysis has been completed for the streamflow record at the 210093 (Kingdon Ponds near Parkville) gauge. A flood frequency analysis enables the magnitude of floods of a selected probability of exceedance to be estimated by statistical analysis of recorded floods. Methods have been developed that allow a probability distribution to be fitted mathematically to observed data so that flood magnitudes of required probabilities can be calculated. These procedures are outlined in Chapter 2, Book 3 of the 2019 edition of 'Australian Rainfall and Runoff'.

The procedures apply primarily to peak discharges at a site and generally should not be applied to peak water levels. This is because the distribution of water level at a site can include discontinuities due to sudden changes in cross-sectional area as discharge increases. Furthermore, the relationship between flood stage and discharge may vary throughout the period of record due to changes in the river channel geometry caused by scouring or bank erosion.

The use of a partial series is recommended if the floods of interest are relatively frequent events (in the order of 0.2 EY or more frequent). Accordingly, the flow record was analysed based on an annual series, which adopts the maximum instantaneous discharge in each calendar year on record.

5.3.1. Review of Flow Record

To undertake a valid flood frequency analysis at least 10 to 15 years of streamflow data is required. The data should constitute a random sample of independent values from a homogenous population (*Australian Rainfall and Runoff 2019*). The streamflow record for the Kingdon Ponds gauge had 51 years (1972 to present) and as such is suitable for a flood frequency analysis.

The full streamflow record was downloaded from the Water NSW website for the flood frequency analysis. As a check, the most recent rating table available on the Water NSW website (dated November 2021) was applied to the annual maximum stream levels at the 210093 gauge. This verified that the annual maximum flows were reliable.

The ten largest historic flood events for the recorded at the 210093 gauge are listed in **Table 5-1**.

Table 5-1 Ranking of peak flows recorded at the 210093 Kingdon Ponds near Parkville gauge

Rank	Year of Event	Peak Flow	Estimated Frequency of Event
1	1976	276.1	1 in 40.1 AEP
2	1992	256.3	1 in 24.7 AEP
3	2000	222.3	1 in 16.3 AEP
4	2021	202.0	1 in 12.1 AEP
5	1998	163.2	1 in 9.7 AEP
6	2022	141.1	1 in 8.0 AEP
7	1977	130.6	1 in 6.9 AEP
8	2007	105.1	1 in 6.0 AEP
9	1978	83.0	1 in 5.3 AEP
10	1996	76.0	1 in 4.8 AEP

A review of the flow record confirmed the independence of the annual maximum flows (i.e., the maximum flows in consecutive years are not attributed to the same rainfall event).

It is important to consider the 1955 historic flood event as part of the flood frequency analysis as it has been identified to be the largest flood to be recorded in the study area. Although the Kingdon Ponds gauge was not active at the time, the use of binomial data censoring was adopted to include the 1955 flood event for consideration in the flood frequency analysis.

5.3.2. Frequency Distribution

Several types of probability distributions are available for flood frequency analysis. ARR 2019 recommends the following two distributions be used when analysing an annual series:

- the Generalised Extreme Value (*GEV*) distribution (*also known as the Gumbel distribution*); and
- the Log Pearson III (*LP III*) distribution.

In flood frequency analysis, discharges in the series are plotted on a frequency diagram. This has discharge as the ordinate (*linear or log scale*) plotted against annual exceedance probability (AEP) or average recurrence interval (ARI) as the abscissa (*probability scale*). For the abscissa (*x axis*) Normal, Exponential or Gumbel (*Extreme Value Type I*) probability scales are most commonly used.

The type of plot chosen is generally a convenience and also allows for the presentation of data in such a way that deviations from the distribution assumed by the axes can be easily assessed.

Each discharge in the annual series was given a "plotting position" (PP); that is, an AEP for plotting purposes, using the recommended formula in ARR 2019, which is:

$$\mathrm{PP} = \frac{m - 0.4}{n + 0.2}$$

where m is the rank in the flood series (*the highest flood in the series having rank m = 1*), and N is the number of peaks in the record.

For this analysis, both the GEV and the LP III distributions were fitted to the available data.

5.3.3. Censoring of Data

There may be situations in which low peak flows may be recorded in an annual series which is not associated with any significant storm event. These low flows are not representative of physical processes driving large floods but may influence the results of the flood frequency analysis. These flows are termed Potentially Influential Low Flows (*PILFs*).

ARR2019 recommends using the multiple Grubbs-Beck test (*developed by Cohn et al, 2013*) to identify any unusually low flows and thus define a threshold for censoring discharges. The test is recommended to be used in conjunction with a visual assessment of the fitted frequency curves.

5.3.4. Results of the Flood Frequency Analysis

The flood frequency analysis at the Kingdon Ponds gauge was completed using the FLIKE flood frequency analysis tool. FLIKE is a flood frequency analysis tool that provides a comprehensive Bayesian analysis for a probability model fitted to gauged and censored historic data. FLIKE outputs include text and graphical outputs showing the historic data used, results, predicted distribution plots, quantiles and confidence limits.

A range of options were tested in FLIKE to determine the best fit for the recorded flows, including several types of probability distributions and with / without censoring of the data. It was found that the adoption of the Log-Pearson III probability distribution model using the Bayesian inference method and application of the multiple Grubbs Beck test to censor Potentially Influential Low Flows (PILFs) yielded the best fit for this streamflow record.

The fitted data is shown graphically in **Figure 5-1**. It is also summarised in **Table 5-2**.

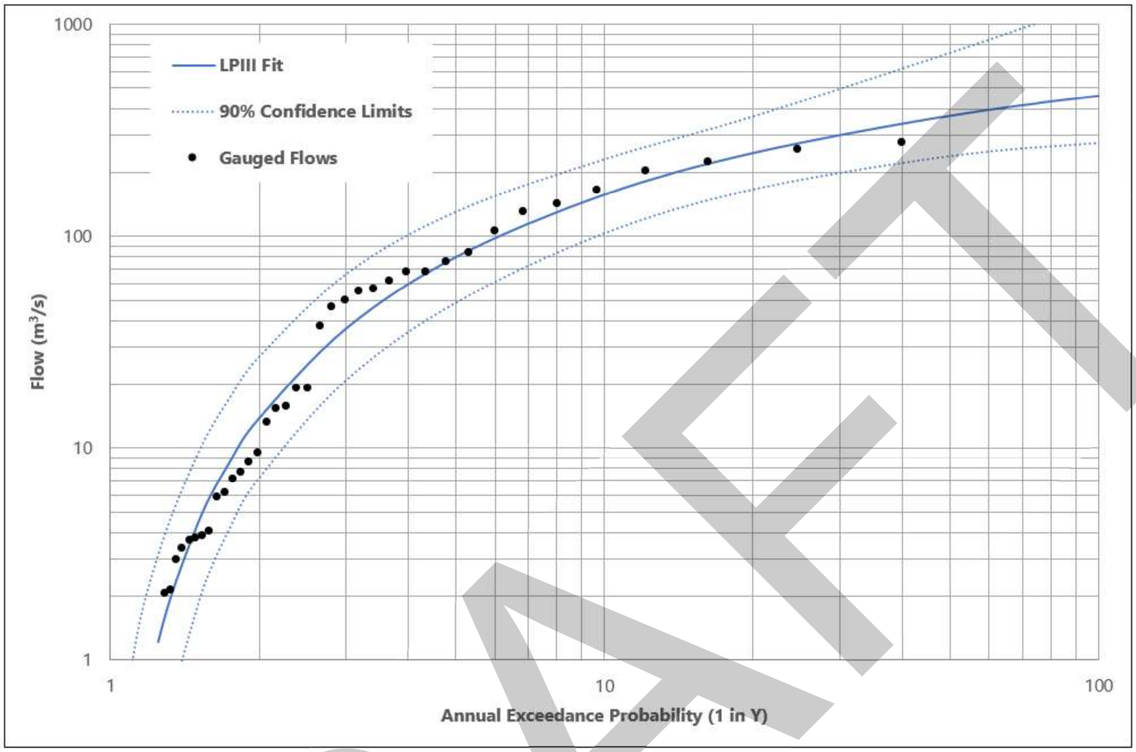


Figure 5-1 Recorded Flows fitted with the Log Pearson III Distribution

Table 5-2 Results of the Flood Frequency Analysis at the 210093 Gauge

AEP (1 in Y)	FFA Predicted Flow (m^3/s)	90% Lower Bound Flow (m^3/s)	90% Upper Bound Flow (m^3/s)
2	13.8	7.3	27.1
5	79.8	48.8	130.8
10	157.1	103.9	231.4
20	246.7	167.1	367.9
50	369.5	240.0	735.6
100	458.1	276.7	1255.3
200	539.4	298.3	1867.3
500	633.1	311.4	3230.6

5.4. Model Calibration – November 2021 Event

Worley Consulting has calibrated the WBNM hydrologic model and the TUFLOW hydraulic model to the November 2021 historic flood event through a process of applying recorded rainfall and adjusting model parameters to achieve improved matches to gauged hydrographs and observed flood behaviour.

The calibration data, process and results are described in the following.

5.4.1. Hydrometric Data

There were 11 active rainfall gauges in the vicinity of the Scone catchment during the November 2021 flood event, comprising eight pluviometers and three daily-read gauges (refer **Table 5-3**).

Table 5-3 Summary of Hydrometric Gauges for the November 2021 Event

Gauge No.	Gauge Name	Gauge Type	Rainfall total to 9:00 am on 26/11 (mm)	Rainfall total to 9:00 am on 27/11 (mm)
61363	Scone Airport AWS	Pluviometer	45.4	20.4
61392	Murrurundi Gap AWS	Pluviometer	48.2	14.6
210061	Pages R at Blandford	Pluviometer	34.8	16.8
210093	Kingdon Ponds near Parkville	Pluviometer / Water Level	49.6	18.8
210118	Isis R at Stick-Me-Up Bridge	Pluviometer	25.8	16.4
210124	Dart Brook at Yarrandi Bridge	Pluviometer	49.4	20.6
561100	Wingen	Pluviometer	42	25.5
561101	Cressfield	Pluviometer	55.5	25
61360	Scone (Kingdon Ponds)	Daily-Read / Water Level	43.5	17
61402	Scone (Stoney Creek)	Daily-Read	64	48
61431	Murrurundi (Haydon St)	Daily-Read	55	19.2

The 210093 and 61360 gauges also recorded water level data during this event. The locations of these hydrometric stations were shown in **Figure 3-4**.

It is noted that a rating curve was not provided for the water level data from the 61360 gauge. To enable a direct comparison with flow hydrographs simulated by the WBNM hydrologic model, the recorded water level hydrographs must be converted to flows. Details on the rating curves used to convert the recorded water level hydrograph into a flow hydrograph are provided in **Appendix A**.

A cumulative rainfall plot for the period from 18:00 on 25 November to 18:00 on 26 November is presented in **Figure 5-2**.

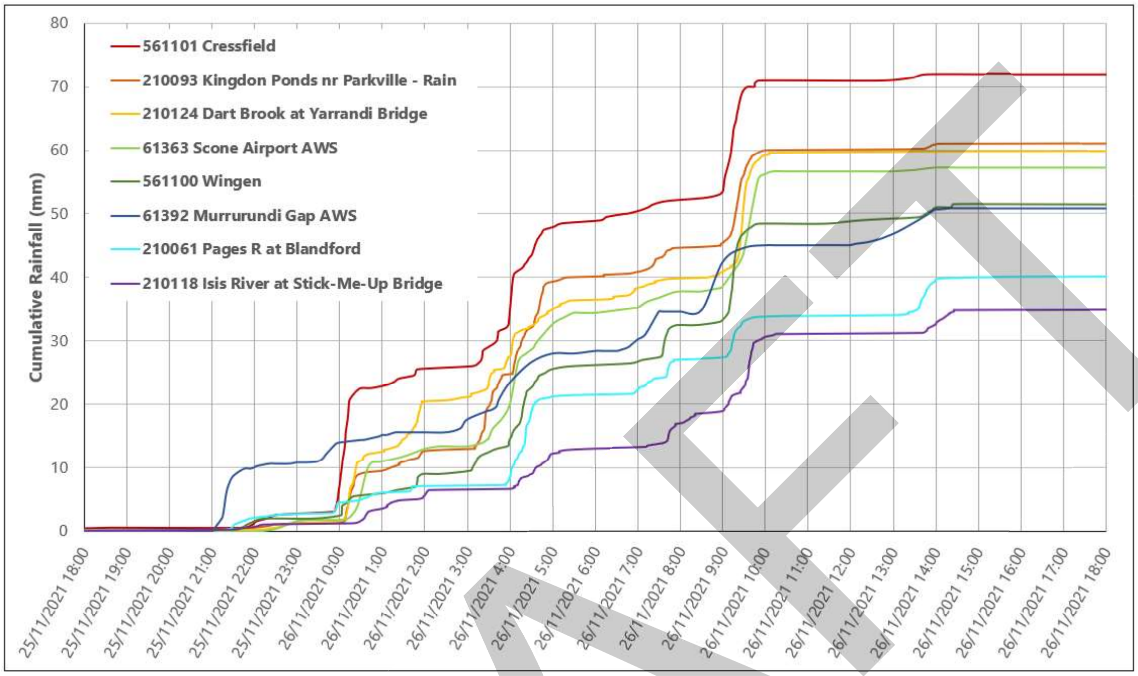


Figure 5-2 Cumulative Rainfall Plot for the November 2021 Event

In general, rainfall intensity appears to decrease moving from west to east across the Kingdon Ponds catchment. The cumulative rainfall plot indicates that a first burst of rainfall occurred towards the western side of the catchment just after midnight on 26 November. A more intense second burst of rainfall was then recorded by all gauges between 3:00 am and 5:00 am that same morning. This was followed by a third burst of rainfall about five hours later at around 9:00 am.

5.4.2. Hydrologic Model Calibration

Rainfall Data

The recorded rainfall data from the 11 gauges listed above was applied in the WBNM hydrologic model for the November 2021 calibration. Data from the three daily rainfall stations were also included by adopting temporal patterns from a nearby pluviometer:

- The temporal pattern from the 61363 gauge was applied to the daily rainfall totals at the 61360 gauge;
- The temporal pattern from the 61392 gauge was applied to the daily rainfall totals at the 61431 gauge; and
- The temporal pattern from the 210061 gauge was applied to the daily rainfall totals at the 61402 gauge.

It is noted that the Scone (Stoney Creek) gauge (*no. 61402*) recorded a significantly higher rainfall total than the nearby gauges. This could be a result of either a gauge error or a very localised burst of rainfall caused by an orographic effect attributed to the location of this gauge in the mountainous areas of Towarri National Park. A factor of 0.8 was applied to the daily rainfall totals at the 61402 gauge to reduce the influence of this gauge within the hydrologic model, as the WBNM software determines rainfall depths across each sub-catchment using an inverse distance weighting algorithm.

Additionally, the lower intensity rainfall recorded at the Isis River gauge (*no. 210118*) was replicated near the eastern catchment boundary to simulate the expected lower intensity rainfall in this area.

Hydrologic Model Parameters

Calibration of the hydrologic model involved modification of the WBNM runoff lag factor 'C' and stream routing lag factor 'F', as well as initial loss (IL) and continuing loss (CL) rates.

The calibration began with default 'C' and 'F' parameters of 1.6 and 1.0 respectively. These initial simulations highlighted the following about the catchment response to rainfall in the 2021 flood event:

- Generally little flow reached the gauges prior to the arrival of the main flood wave
- The water levels at both Kingdon Ponds gauges (no. 210093 and 61360) rose very quickly. The 210093 gauge in particular was very 'flashy' in shape with a sharp, steep rise and fall.
- Despite the steep rise in the hydrograph shapes, attenuation in the timing of the flood wave between the upper, mid and lower catchment was significant.

The above findings suggested the following with regard to the required model parameters:

- A suitable initial loss would be required to achieve the delay in the initial rise of the main flood wave
- A low runoff lag factor 'C' would be required to replicate the flashy nature of the flood hydrographs
- There would be a balance required in the stream routing lag factor 'F' to maintain the flashy hydrograph shape lower in the catchment while achieving the required attenuation in the timing of the flood wave.

The process of calibrating the model parameters is discussed in the following, with final calibrated parameter values presented in **Table 5-4**:

- The model was first calibrated to the gauge along Kingdon Ponds near Parkville (no. 210093) as the gauge lower in the catchment (i.e., 61360 Scone) is dependent on this gauge in the middle catchment.
- The runoff lag factor 'C' value was stepped lower until a suitable hydrograph shape and peak flow was achieved at the upper gauges, arriving at a value 0.9. Even lower values may have resulted in preferable hydrograph shapes but would have negatively impacted hydrograph timing lower in the catchment and would begin to move outside the ranges for 'C' presented in WBNM documentation.
- Some variation in stream lag factor 'F' was applied across the catchment to assist in the replication of the flashy hydrograph shapes while achieving a desirable level of attenuation of the flood wave moving downstream. Factors such as the catchment slope, area to stream length ratio, degree of channel incision, degree of channel meander and vegetation were considered.
- The stream routing factor 'F' in the upper catchment was refined downward to values between 0.5 and 1.0 to assist in the replication of the flashy hydrograph shape at the 210093 gauge.
- Lower in the catchment 'F' was generally maintained at 1.0 except in a handful of sub-catchments which had a very high stream length relative to their area. The WBNM stream lag formulation

estimates stream length from the sub-catchment area and therefore assumes that the stream length to area ratio is equal between sub-catchments. Six sub-catchments with a very high stream length to area ratio were identified and assigned 'F' values of between 2.0 and 6.0 based on the size of the ratio relative to the average for the catchment. These sub-catchments primarily affected lag between the 210093 Kingdon Ponds near Parkville and 61360 Scone gauges.

- A range of initial loss and continuing loss values were tested based on values presented in ARR 1987, ARR 2019, and the ARR Data Hub. An initial loss value of 18 mm was adopted as required in the mid and lower catchment to match the sudden arrival of the flood wave at the 61360 Scone gauges. In the upper catchment such a loss value negatively impacted the replication of peak flood flows and a lower value of 10 mm was adopted.
- Results were less sensitive to continuing loss, with a value of 2.5 mm/hr adopted for calibration simulations.

Table 5-4 Calibrated WBNM Model Parameters

Area	Runoff Lag Factor 'C'	Stream Routing Lag Factor 'F'	IL (mm)	CL (mm/h)
Upper Catchment	0.9	0.5 - 1.0	10	2.5
Mid to Lower Catchments	0.9 (except C=1.3 for Figtree Gully catchment, refer Section 5.6)	Generally 1.0; Higher values where high stream length to area ratio	18	2.5

Comparison of Simulated WBNM Hydrographs against Recorded Hydrographs

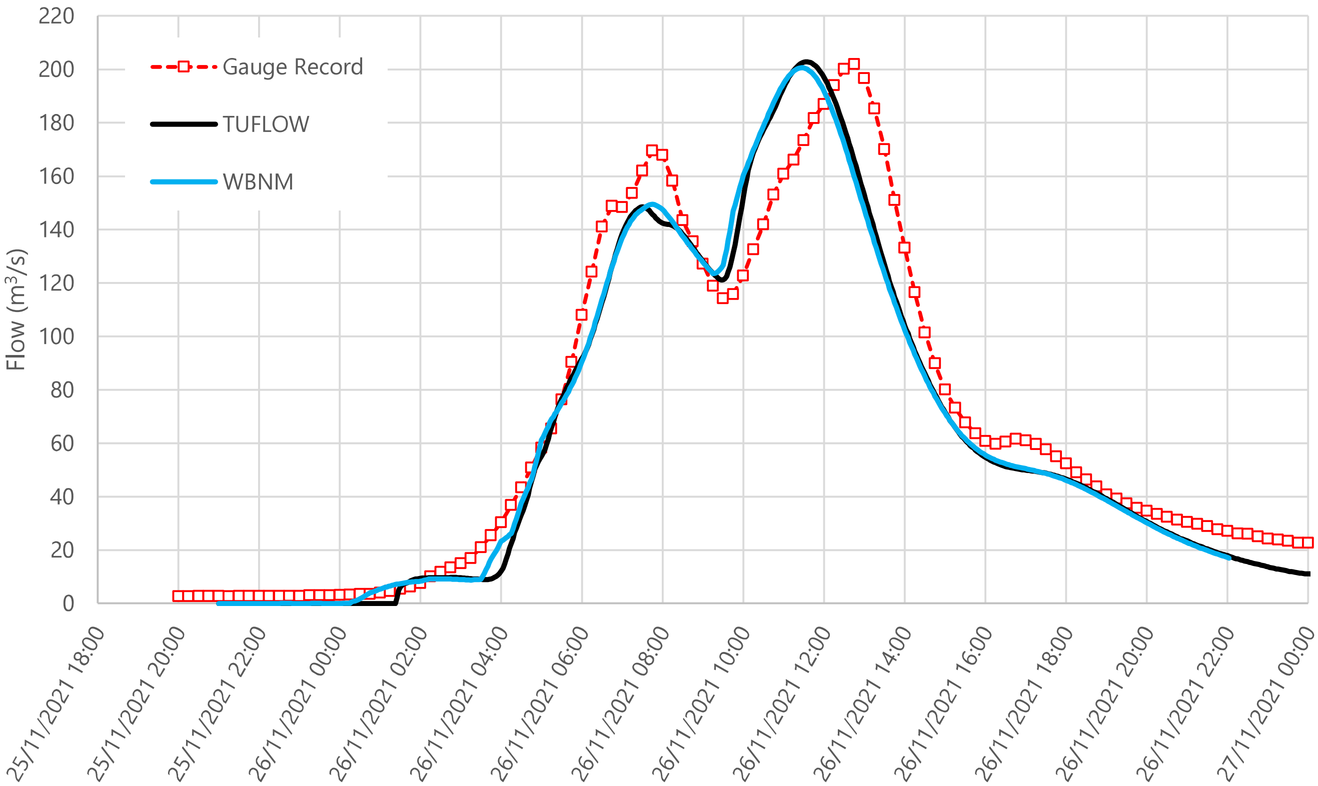
Results of the WBNM model calibration for the November 2021 flood are presented in **Figure 5-3** comprising comparisons of simulated and gauged flood hydrographs. The results are summarised in the following.

- <u>210093 Kingdon Ponds near Parkville</u>
  - The shape and timing of the flood hydrograph is generally well replicated by the model, though the first flood peak is slightly underestimated.
  - The peak simulated flow (200.6 m^3/s) is very close to the gauged peak flow (202.0 m^3/s).
  - The achieved result is considered appropriate and provides a suitable balance between matching the gauged hydrograph timing, shape and peak flow.
- <u>61360 Scone (Kingdon Ponds)</u>
  - The peak simulated flow lies above the 'upper' estimate of gauged flow.
  - The gradient of the rising limb of the hydrograph is reasonably well replicated by the model, though it occurs earlier than the gauged flood hydrograph.
  - The WBNM model does not reliably replicate the shape of the flood hydrograph.

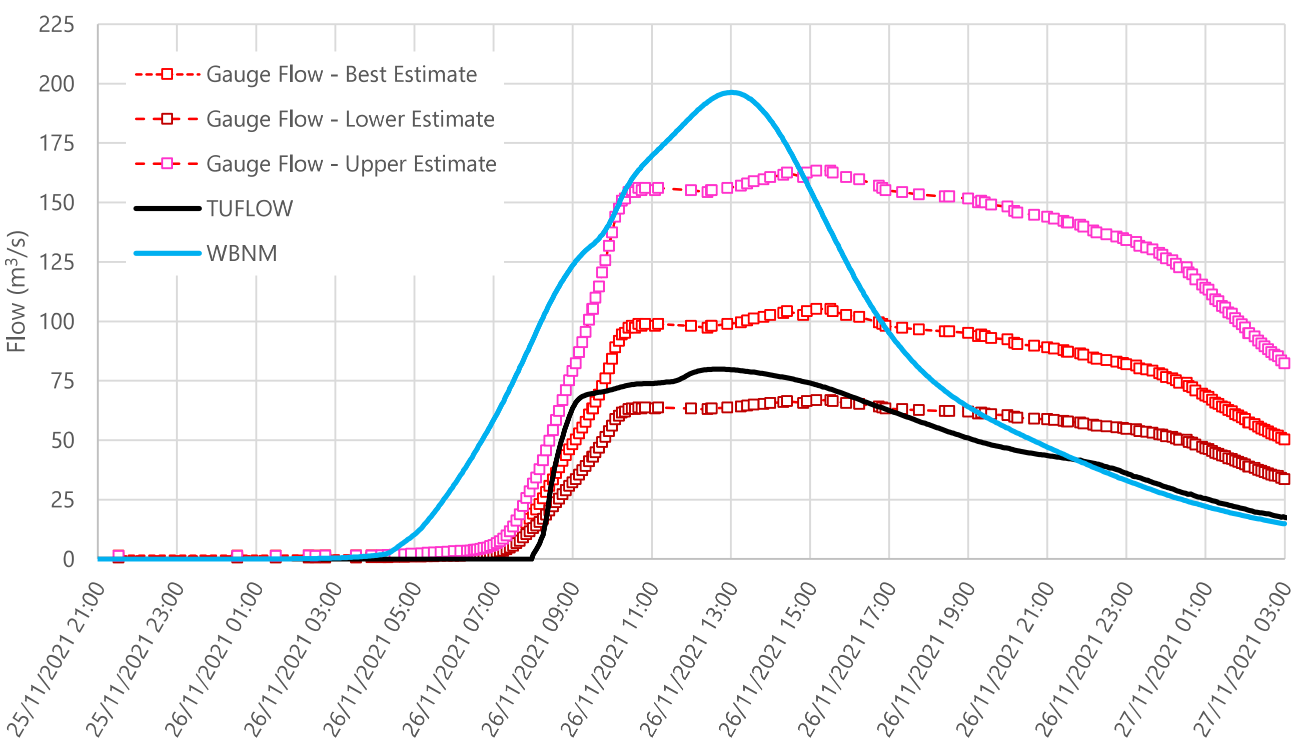
FIGURE 5-3

DRAFT

210093 Kingdon Ponds near Parkville - Simulated vs Gauged Flows



61360 Scone (Kingdon Ponds) - Simulated vs Gauged Flows



UPPER HUNTER SHIRE COUNCIL

Prepared by:

worley consulting

211019_Scone_TUFLOW.qgs

fg311015-00018_220304_ReportFigs_A4P.pdf

COMPARISON OF SIMULATED AND GAUGED FLOWS FOR THE NOV 2021 EVENT

5.4.3. Hydraulic Model Calibration

The hydraulic model calibration was assessed through the comparison of recorded and simulated flow hydrographs at the 210093 and 61360 stream gauges. The locations of these gauges with respect to the TUFLOW model domain had been previously shown in **Figure 4-2**. To better represent conditions during the November 2021 event, the Scone Bypass development is included in the model build.

Comparison of Simulated TUFLOW Hydrographs against Recorded Hydrographs

Results of the TUFLOW model calibration for the November 2021 flood are presented in **Figure 5-3** comprising comparisons of simulated and gauged flood hydrographs. The results are summarised in the following.

- 210093 Kingdon Ponds near Parkville
  - The shape and timing of the TUFLOW flow hydrograph closely matches the WBNM flow hydrograph. This is expected given that the 210093 gauge is located close to the upstream inflow boundary of the model, and hence flood routing at this stage would be governed by the WBNM routing and lag factors.
  - Both modelled flow hydrographs compare well to the recorded flow hydrograph.
  - Similar to the discussion in **Section 5.4.2**, the TUFLOW flow hydrograph provides a suitable balance between matching the gauged hydrograph timing, shape and peak flow.
- 61360 Scone (Kingdon Ponds)
  - The peak simulated flow lies between the 'lower' and 'best' estimates of gauged flow and is considered appropriate.
  - The gradient of the rising limb of the hydrograph is also reasonably well replicated by the TUFLOW model.
  - The shape and timing of the TUFLOW hydrograph presents a much closer match to the gauged hydrograph when compared to the WBNM hydrograph. This signifies that the complex nature of the floodplain (e.g., the high degree of meandering in the Kingdon Ponds channel and the expected breakout of flows) is well represented by the flood routing in the TUFLOW model.

Comparison of TUFLOW Model Results against Drone Footage

The extent of flooding predicted by the TUFLOW hydraulic model was compared against drone footage captured by a Council staff member. The video footage was filmed at around 1:40 pm on 26 November, which is close to the peak of the flood event.

The comparison between the flood model results and the available drone footage indicates that the TUFLOW model was able to reasonably replicate the extent of flooding during the peak of the November 2021 event. Some key areas where the simulated flood extent compared well against the recorded footage include:

- Aberdeen Street to the south of the Aberdeen Street / Liverpool Street intersection;
- Minor overtopping of Liverpool Street between Parsons Gully and Kingdon Ponds;
- The Parsons Gully / Kingdon Ponds floodplain to the north of Liverpool Street, between Scone and Satur.

Further details and stills of the drone footage are provided in **Appendix A**.

5.4.4. Discussion of Flows Breaking Out from Kingdon Ponds

Further analysis of the flood model results indicates that a significant proportion of the flows along the Kingdon Ponds watercourse 'breaks out' of the channel and spill into Parsons Gully during the November 2021 flood event. This flow breakout from Kingdon Ponds is shown in **Figure 5-5** overleaf and occurs at several meander bends downstream of Parkville.

It was determined that the occurrence of these cross-catchment flows was the primary cause for the misestimation of the WBNM flow hydrograph at the 61360 gauge. Traditional hydrologic models are not able to reliably represent such cross-catchment flows and therefore, the recorded flow in Kingdon Ponds at the Liverpool Street crossing near the 61360 gauge is much less than the flow predicted by the WBNM model.

In order to confirm that the WBNM model reliably estimates peak flows along the Kingdon Ponds / Parsons Gully floodplain near Liverpool Street, the TUFLOW and WBNM model results were compared. TUFLOW model flows along Kingdon Ponds and Parsons Gully were extracted and summed for comparison with flows extracted from the WBNM model. The comparison shows that the summed TUFLOW peak flows provides a good match to the WBNM peak flow at Kingdon Ponds near Liverpool Street (refer **Figure 5-4**). Therefore, this validates the ability of the WBNM model to predict peak flows along the Kingdon Ponds / Parsons Gully floodplain near Liverpool Street.

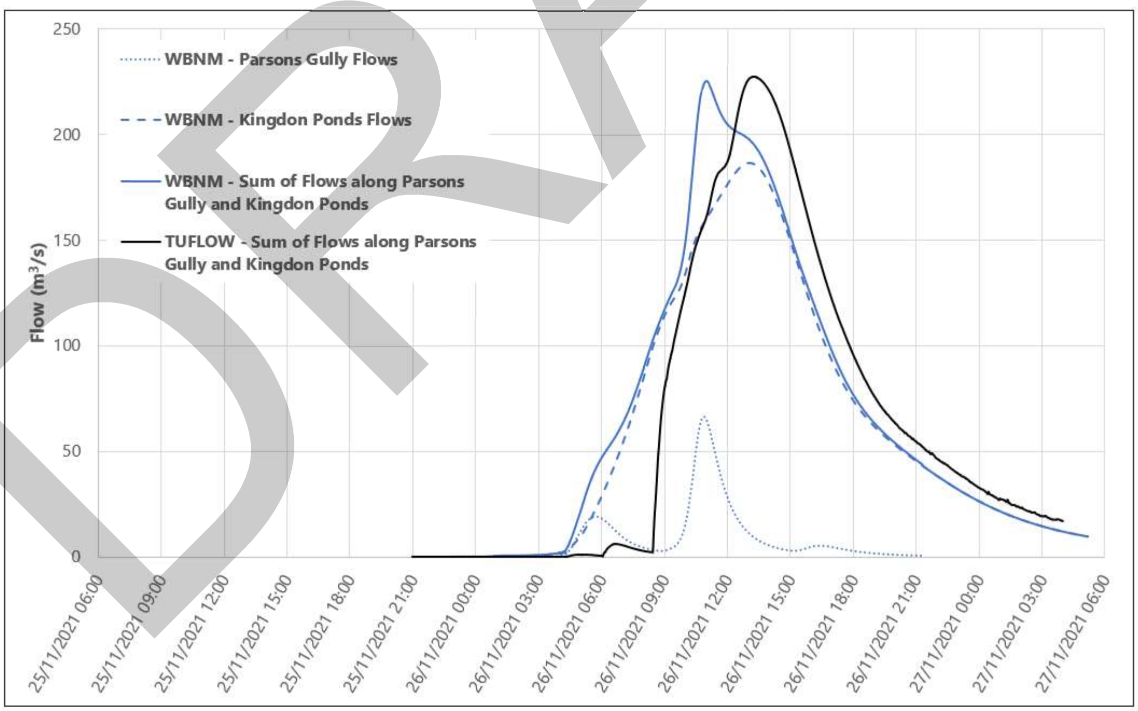
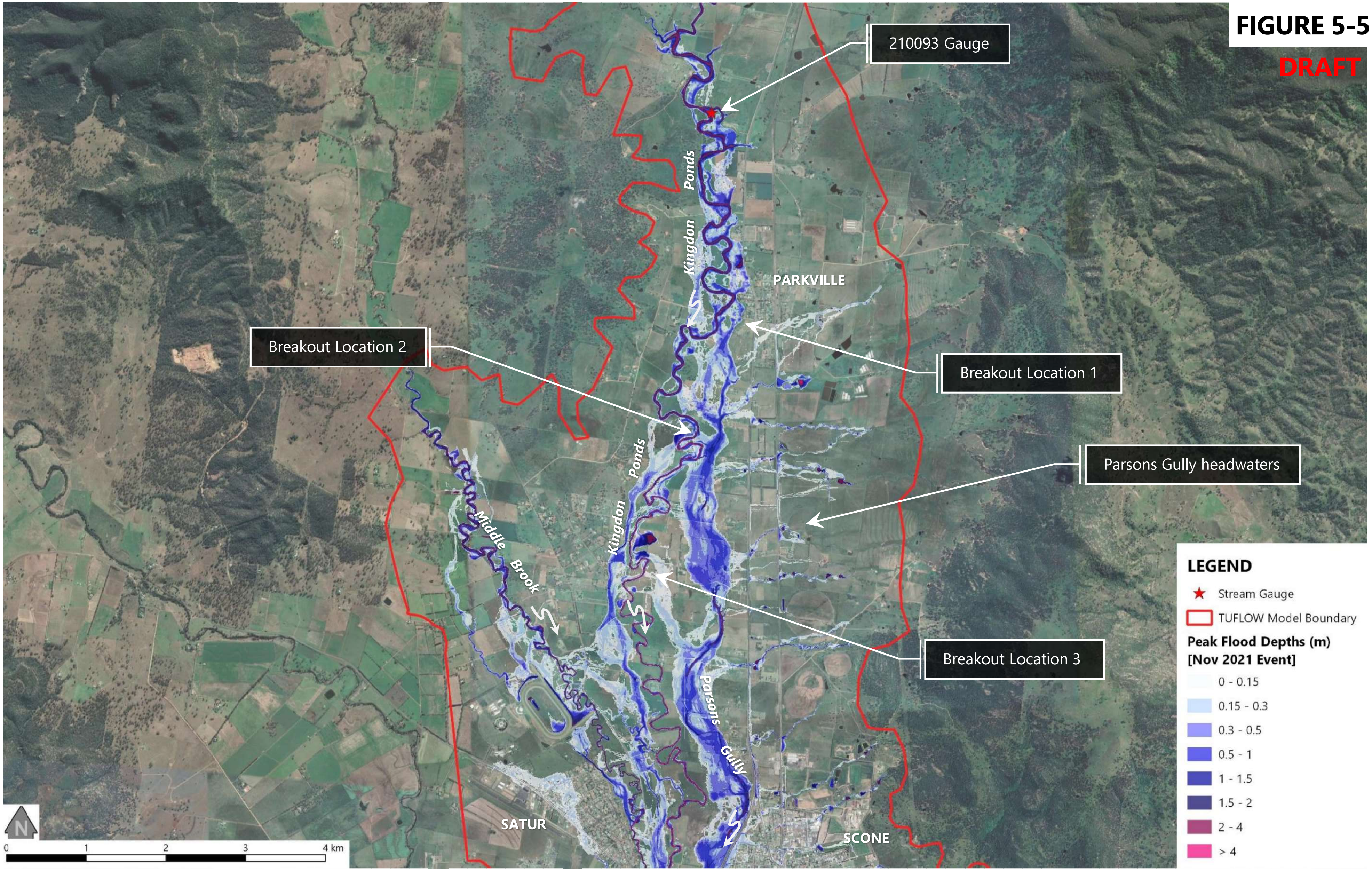


Figure 5-4 Comparison of TUFLOW & WBNM Hydrographs at Kingdon Ponds and Parsons Gully near Liverpool St

FIGURE 5-5

DRAFT



Prepared by: Worley Consulting

UPPER HUNTER SHIRE COUNCIL

LOCATION OF FLOW BREAKOUTS ALONG KINGDON PONDS DURING THE NOV 2021 EVENT

5.5. Model Validation – December 2007 Event

In order to further verify that the developed WBNM hydrologic model is able to reliably replicate actual flood behaviour, simulation of a second historic flood event was undertaken. The December 2007 event was selected as this represents one of the highest recorded flood levels at the 210093 Kingdon Ponds near Parkville gauge during the period of greater hydrometric station availability for the Scone catchment from 2003 onwards.

5.5.1. Hydrometric Data

There were eight (8) pluviometers and five (5) stream gauges which were active in the vicinity of the Scone catchment during the December 2007 flood event (refer **Table 5-5**).

Table 5-5 Summary of Hydrometric Gauges for the December 2007 Event

Gauge No.	Gauge Name	Gauge Type	Rainfall total to 9:00 am on 22/12 (mm)	Rainfall total to 9:00 am on 23/12 (mm)
61360	Scone (Kingdon Ponds)	Pluviometer / Water Level	28	10
61392	Murrurundi Gap AWS	Pluviometer	14	25.4
210061	Pages R at Blandford	Pluviometer	8.2	17.4
210093	Kingdon Ponds near Parkville	Pluviometer / Water Level	33.2	14
561099	Dry Creek	Pluviometer / Water Level	27	8.5
561100	Wingen	Pluviometer / Water Level	15.5	24
561101	Cressfield	Pluviometer / Water Level	34.5	18.5

All gauges except for the 61392 and 210061 gauges also recorded water level data during this event. The locations of these hydrometric stations were shown in **Figure 3-4**.

It is noted that a rating curve was not provided for the water level data obtained from the 61360, 561099, 561100 and 561101 gauges. To enable a direct comparison with flow hydrographs simulated by the WBNM hydrologic model, the recorded water level hydrographs must be converted to flows. Details on the rating curves used to convert the recorded water level hydrograph into a flow hydrograph are provided in **Appendix A**.

A cumulative rainfall plot for the period from 00:00 on 22 December to 00:00 on 23 December is presented in **Figure 5-6**.

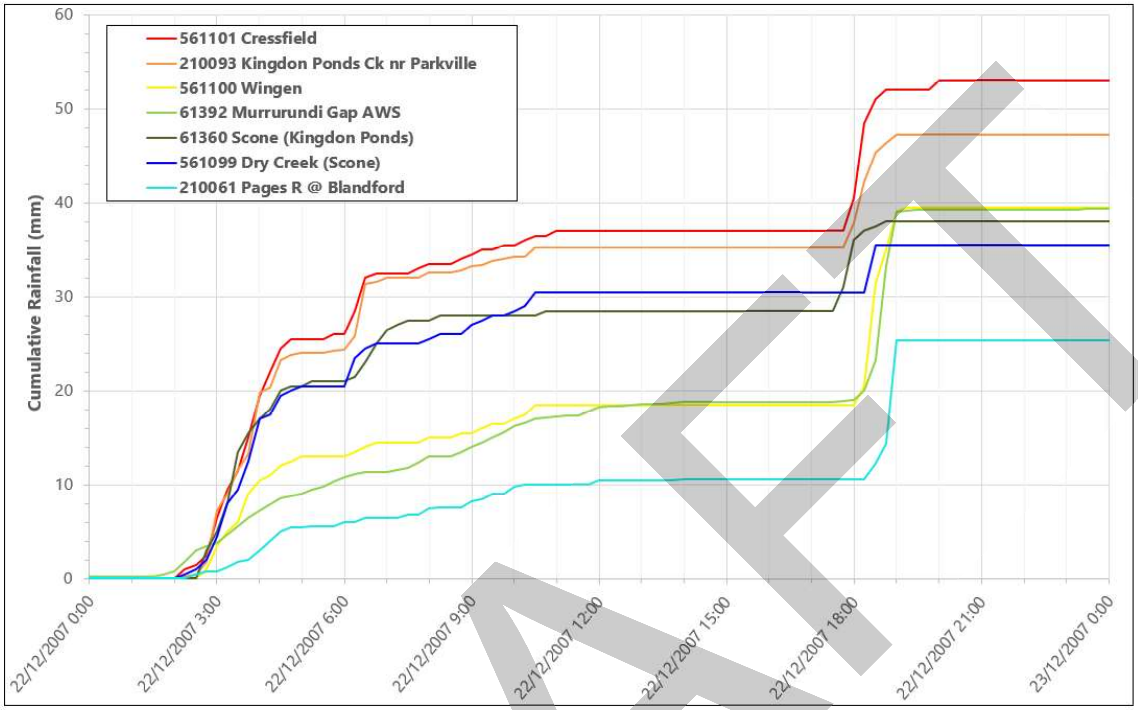


Figure 5-6 Cumulative Rainfall Plot for the December 2007 Event

The cumulative rainfall plot indicates that there were two main bursts of rainfall occurred from about 2:00 am and 6:00 pm on 22 December 2007 respectively. The first burst of rainfall was more intense in the middle and lower catchment, while the second burst of rainfall was more intense in the upper catchment.

5.5.2. Hydrologic Model Verification

Rainfall Data

The rainfall data from the eight pluviometers were applied to the WBNM model without any changes or modifications.

Hydrologic Model Parameters

The calibrated parameters from the November 2021 event were adopted without modification with the exception of initial loss and continuing loss. Initial loss values of 21 mm and 50 mm were adopted in the upper catchment and the mid-lower catchments, respectively. A continuing loss of 1.9 mm/hr was applied.

A higher initial loss was required for the model verification simulations in order to match the recorded flow hydrographs.

Comparison of Gauged and Simulated Hydrographs

Results of the WBNM model verification to the December 2007 flood are presented in **Figure 5-7** which shows comparisons between simulated and gauged flood hydrographs. The results are summarised in the following.

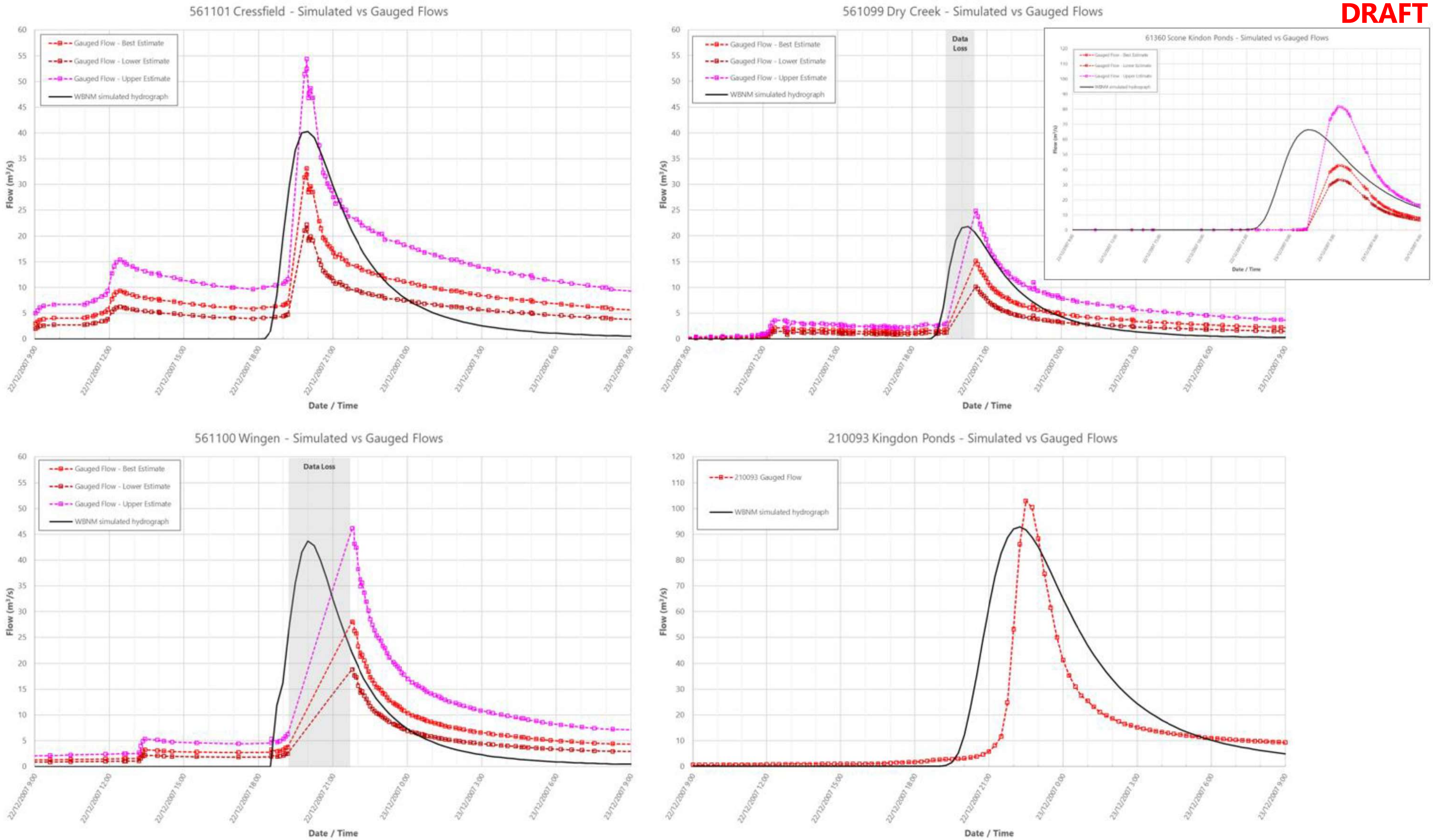
- 561101 Cressfield
  - The overall shape and timing of the flood hydrograph is well replicated by the model
  - The peak simulated flow lies between the 'best' and 'upper' estimates of gauged flow. This was typical for the gauges with estimated rating curves and is considered appropriate, as lower peak flows at these gauges would have resulted in an underestimate of flows at the 210093 Kingdon Ponds near Parkville gauge
- 561099 Dry Creek
  - The expected shape and timing of the flood hydrograph during the period of data loss appears to be well replicated by the model
  - The peak simulated flow lies between the 'best' and 'upper' estimates of gauged flow and is considered appropriate
- 561100 Wingen
  - The expected shape and timing of the flood hydrograph during the period of data loss appears to be well replicated by the model
  - The peak simulated flow lies between the 'best' and 'upper' estimates of gauged flow and is considered appropriate
- 210093 Kingdon Ponds near Parkville
  - The shape and timing of the flood hydrograph is generally well replicated by the model, though the gauged hydrograph is somewhat 'flashier' in nature with shorter, steeper rising and falling limbs. In order to simulate such a hydrograph shape lag factors would have to have been further reduced, which would have negatively impacted flood timing.
  - The peak simulated flow (93 m^3/s) is somewhat lower than the gauged peak flow (103 m^3/s). Achieving a higher simulated peak flow would have required a reduction in lag factors and/or initial loss, which would have negatively impacted flood timing.
  - The achieved result is considered appropriate and provides a suitable balance between matching the gauged hydrograph timing, shape and peak flow.
- 61360 Scone (Kingdon Ponds)
  - The peak simulated flow lies between the 'best' and 'upper' estimates of gauged flow and is considered appropriate. The simulated flood peak occurs approximately 2 hours before the gauged peak.
  - The shape and timing of the flood hydrograph is reasonably well replicated by the model, though it occurs earlier than the gauged flood hydrograph and yet is somewhat less 'flashy'.
  - An improved match in timing could have been achieved by increasing stream lag factors, however this would have negatively impacted the hydrograph shape and peak flow. It is considered preferable to maintain the hydrograph shape and peak so as not to underestimate the potential severity of flooding.

- It is noted that the majority of the watercourse between the 210093 Kingdon Ponds near Parkville gauge and this gauge will be represented in the TUFLOW hydraulic model. Therefore, the upcoming design flood estimation will not be heavily reliant on the stream routing behaviour of the WBNM model in this area. Accordingly, the achieved calibration at this location is considered suitable for the purposes of the study.

The results of the December 2007 flood simulations are considered to constitute a successful model verification and provide further evidence and confidence in the ability of the developed WBNM hydrologic model to suitably replicate historic flood behaviour.

FIGURE 5-7

DRAFT



Prepared by:

WBNM HYDROLOGIC MODEL CALIBRATION RESULTS
DECEMBER 2007 HISTORIC EVENT

5.5.3. Hydraulic Model Verification

The hydraulic model verification was assessed through the comparison of recorded and simulated flow hydrographs at the 210093 and 61360 stream flow gauges. The locations of these gauges were shown in **Figure 4-2**. To better represent conditions during the December 2007 flood event, the Scone Bypass development was omitted from the model build.

It is noted that there is a general lack of flood marks and available footage for this historic event. Therefore, the verification of the hydraulic model will be completed primarily by comparing gauged and simulated flow hydrographs.

Comparison of Simulated TUFLOW Hydrographs against Recorded Hydrographs

The comparison of simulated and recorded flood hydrographs is presented in **Figure 5-8**. This comparison is discussed further in the following.

210093 Kingdon Ponds near Parkville

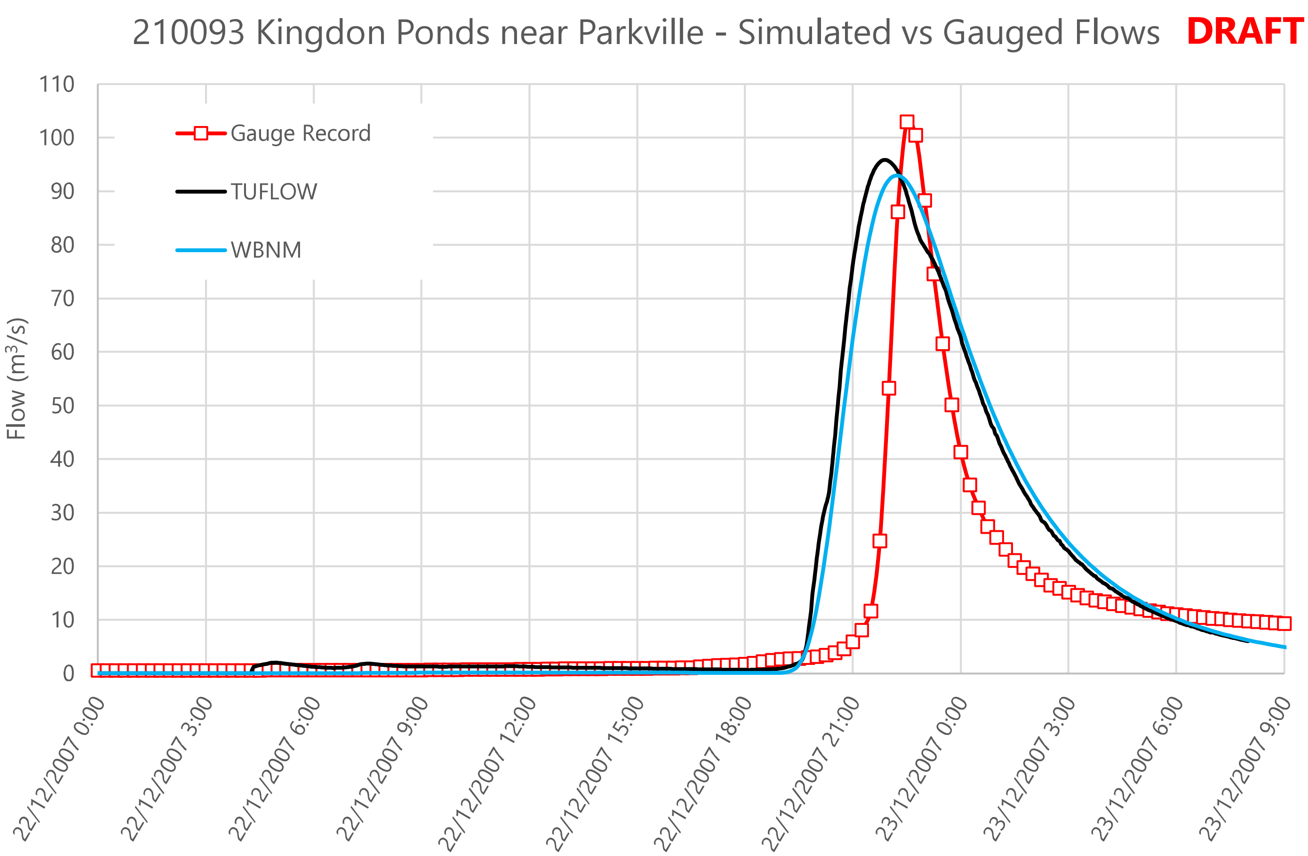
- The shape and timing of the TUFLOW flow hydrograph closely matches the WBNM flow hydrograph. This is expected given that the 210093 gauge is located close to the upstream inflow boundary of the model, and hence flood routing at this gauge would be governed by the WBNM routing and lag factors. Both modelled flow hydrographs generally compare well to the recorded flow hydrograph.
- Similar to the discussion in **Section 5.4.3**, the TUFLOW flow hydrograph provides a suitable balance between matching the gauged hydrograph timing, shape and peak flow.
- The timing of the peak in the TUFLOW flood level hydrograph provides a close match to the recorded flood level hydrograph at the 210093 gauge.

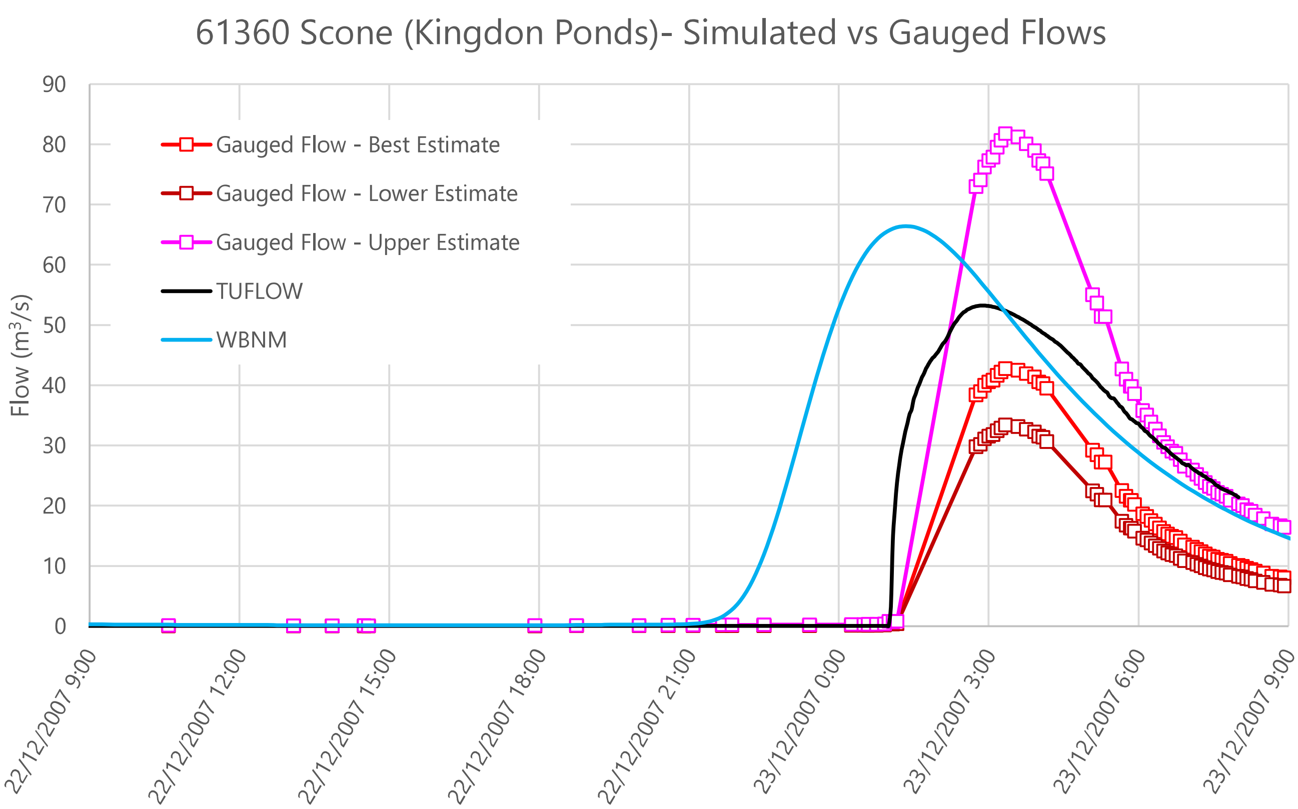
61360 Scone (Kingdon Ponds)

- The TUFLOW simulated peak flow lies between the 'best' and 'upper' estimates of gauged flow and is considered appropriate.
- The shape and timing of the TUFLOW hydrograph presents a closer match to the gauged hydrograph when compared to the WBNM hydrograph. This signifies that the high degree of meandering in the Kingdon Ponds channel is well-represented by the flood routing in the TUFLOW model.
- The peak in the TUFLOW model occurs 90 minutes after the peak flow in the WBNM model. The peak flow in the TUFLOW model occurs only 25 minutes earlier than the recorded peak flow, whereas the WBNM peak flow occurred 2 hours earlier than the recorded peak flow.
- It is noted that the TUFLOW hydrograph presents a closer match to the recorded hydrograph at this gauge when compared to the November 2021 calibration results. This is because there is significantly less flow breaking out of Kingdon Ponds in the December 2007 historic event.

Therefore, the verification results provide confidence in the ability of the TUFLOW hydraulic model to simulate actual flood behaviour in the study catchment. The verification results also indicate that the TUFLOW model is capable of reliably routing the flood wave along the meanders of Kingdon Ponds, which could not be captured in the WBNM model alone.

FIGURE 5-8





UPPER HUNTER SHIRE COUNCIL

Prepared by:

worley consulting

211019_Scone_TUFLOW.qgs

fg311015-00018_220304_ReportFigs_A4P.pdf

COMPARISON OF SIMULATED AND GAUGED FLOWS FOR THE DECEMBER 2007 EVENT

5.6. Findings from the Scone CBD Revitalisation Project

In parallel with its work for the Scone Flood Study, Worley Consulting (*then Advisian*) was engaged by Upper Hunter Shire Council to provide flood and stormwater drainage advice to support the Scone CBD Revitalisation Project. Worley Consulting's role was to investigate flooding within the Scone CBD caused by rainfall in the Figtree Gully catchment and to assess options for reducing the frequency of inundation of properties along Kelly Street.

Throughout the course of the Scone CBD Revitalisation Project and following discussions with Council staff, it was agreed that the WBNM runoff lag factor 'C' should be verified for the Figtree Gully catchment.

Consequently, the February 1992 historic flood event was investigated as part of this verification process. This event was chosen as pluviograph data is available from the nearby gauge at Scone Airport (gauge number 61363). Additionally, although there are no streamflow gauges in the Figtree Gully catchment, the *'Scone Floodplain Management Study and Plan'* (*Bewsher Consulting, 1999*) contains a number of detailed descriptions of the flood behaviour for this event.

Following the model verification process, a value of C = 1.3 was recommended for the Figtree Gully catchment. Further information on the model verification process is provided in **Appendix A**.

5.7. Summary of Key Outcomes from the Model Calibration Process

The key outcomes and findings from the model calibration process are listed in the following.

- A satisfactory model calibration was achieved by adopting a WBNM runoff lag factor of C = 0.9 for the Middle Brook, Kingdon Ponds and Parsons Gully catchments.
- A secondary verification simulation was completed for the Figtree Gully catchment. A WBNM runoff lag factor of C = 1.3 was recommended for the Figtree Gully catchment.
- WBNM stream routing lag factors of between F = 0.5 and F = 6.0 were adopted.
- The flood routing in the TUFLOW model is more reliable than the WBNM flood routing for the Kingdon Ponds / Parsons Gully floodplain between Parkville and Scone. The TUFLOW hydraulic model reliably simulates the complex flood behaviour in this floodplain, including the high degree of channel meander within Kingdon Ponds as well as the occurrence of cross-catchment flows as floodwaters escape the Kingdon Ponds channel and spill into Parsons Gully.

6. Design Flood Estimation

6.1. General

Design flood conditions are estimated from hypothetical design rainfall events that have a particular statistical probability of occurrence. Guidance and data for the estimation of design flood conditions in Australia as provided in *Australian Rainfall and Runoff: A Guide to Flood Estimation* (*ARR 2019*) have been adopted in this study.

The probability of a design event occurring can be expressed in terms of percentage Annual Exceedance Probability (AEP) and provides a measure of the relative frequency and magnitude of the flood event. Flood conditions for the 20%, 10%, 5%, 2%, 1%, 1 in 200 and 1 in 500 AEP design events and the Probable Maximum Flood (PMF) have been investigated in this study.

6.2. Design Flood Events and Scenarios Assessed

The study considered flood behaviour for a range of events and scenarios as outlined in **Table 6-1**.

Table 6-1 Design flood events and scenarios assessed

Scenario ID	Scenario Description	Design Events to be Assessed
2	Design flood events for existing (2023) conditions	20%, 10%, 5%, 2%, 1%, 1 in 200 and 1 in 500 AEP & PMF
4	Design flood events for climate change sensitivity (comparison of 1% AEP with 1 in 200 & 1 in 500 AEP)	1% AEP
7	Design flood event for model parameter sensitivity analysis	5% and 1% AEP
8	Design events for assessment of flood hazard	5% and 1% AEP & PMF
9	Design events for assessment of flood function	5% and 1% AEP & PMF
11	Design events for assessment of flood warning and emergency management	5%, 1% and 1 in 500 AEP & PMF

6.3. Design Rainfall

6.3.1. Design Rainfall Spatial Pattern

Intensity-Frequency-Duration (IFD) data was obtained from BoM for nine (9) locations across the study area. The locations are identified in **Figure 6-1** and provide a good representation of the spatial variation in design rainfall depths.

The data indicates that design storm rainfall intensities are higher in the mountainous areas in the north-west of the catchment between Wingen and Murrurundi. Rainfall intensities are relatively uniform along a north-south axis extending from Wingen, through Parkville and Scone, and onto Aberdeen. Some higher rainfall intensities are expected in the mountainous area near the middle of the catchment, to the north-east of Parkville.

6.3.2. Design Rainfall Depths

Rainfall depths for the 20%, 10%, 5%, 2%, 1%, 1 in 200 and 1 in 500 AEP design events were obtained from the Bureau of Meteorology (BoM) online IFD data tool. As discussed above, data from nine locations was obtained in order to resolve spatial variation in design rainfall depths across the study area.

The Probable Maximum Precipitation (PMP), as used to determine the PMF, was calculated by application of the Generalised Short Duration Method (GSDM) defined by BoM (2003).

An areal reduction factor was not applied for the Figtree Gully catchment and the overland flow catchments that drain urban areas in Scone and Satur. This was considered appropriate due to the small catchment sizes for these areas of interest. The Figtree Gully catchment is approximately 7 km^2 while the overland flow catchments typically do not exceed 2 km^2.

Areal reduction factors for the catchments of Middle Brook, Kingdon Ponds and Parsons Gully were calculated according to procedures described in *Australian Rainfall and Runoff 2019* (ARR 2019).

6.3.3. Design Rainfall Temporal Patterns

To estimate a design flood hydrograph a temporal pattern must be applied to the design rainfall depths to describe how rain falls over time. Traditionally, a single burst temporal pattern has been applied for each design rainfall event and duration; however, this approach has been questioned as a wide variety of temporal patterns is possible.

The ARR 2019 guidelines recommend that 'ensembles' of 10 temporal rainfall patterns that have been derived to represent variability in observed patterns be analysed for each design storm magnitude and duration.

ARR 2019 states that the 10 patterns within an ensemble provide a range of plausible answers, with testing demonstrating that peak flows for a number of the patterns tend to cluster around the mean for most catchments. For the purposes of selecting a single representative design rainfall pattern, the average of the 10 resulting peak flows is taken to be the actual peak design flood flow at a given location. The temporal pattern resulting in a peak flow nearest to (but not more than 5% less than) this average would typically be adopted to determine the design flood hydrograph.

6.3.4. Design Rainfall Losses

Rainfall losses refers to precipitation that does not contribute to direct runoff. During a storm these losses occur primarily due to the processes of interception by vegetation and infiltration into the soil. The initial loss-continuing loss approach is typically used in Australia to account for losses in the rainfall-runoff process and has been adopted for this study.

Initial and continuing loss rates for pervious surfaces have been adopted for this study in accordance with the NSW specific guidance which is accessible from the ARR Data Hub. In light of this guidance, Worley Consulting has considered a range of calibration losses from studies within the Scone catchment as well as studies in nearby catchments. The considered calibration losses are listed in **Table 6-2**.

A wide range of initial losses have been adopted in the various studies for both calibration and design flood simulations. The data listed in **Table 6-2** indicates that adopted initial loss rates have typically fallen within the 20 to 40 mm range.

Adopted continuing losses have typically ranged between 0.5 and 2.5 mm/h.

Worley Consulting has considered the range of design storm loss rates adopted for studies of nearby catchments and has opted to adopt design loss rates of 30 mm and 1.5 mm/h for initial and continuing loss rates, respectively. This represents the approximate average of the calibration and design losses adopted in the previous studies in the vicinity of Scone.

For the PMF, initial and continuing loss rates were adopted in accordance with the guidance outlined in Book 8 Chapter 6 of ARR 2019. Values of 0 mm and 1 mm/h were adopted for the initial and continuing loss rates, respectively.

Table 6-2 Comparison of rainfall loss rates in other studies

Study	Calibration Losses	Losses Adopted for Design Modelling
Scone Flood Study (*DLWC, 1996*)	IL = 10 to 80 mm CL = 2.5 mm/h	IL = 30 to 60 mm CL = 2.5 mm/h
Aberdeen Flood Study (*WMAwater, 2013*)	IL = 5 to 50 mm CL = 1 to 2.5 mm/h	IL = 30 mm CL = 2.5 mm/h
Upper Hunter River Flood Study (*WorleyParsons, 2014*)	IL = 5 to 80 mm CL = 0.5 to 2.5 mm/h	IL = 20 to 40 mm CL = 1 to 2.5 mm/h
Updated Upper Hunter River Flood Study (*Royal Haskoning DHV, 2017*)	IL = 15 to 30 mm CL = 1.5 mm/h	IL = 20 to 50 mm CL = 1.5 mm/h
Current Study (*Worley Consulting, 2024*)	IL = 10 to 50 mm CL = 1.9 to 2.5 mm/h	IL = 30 mm CL = 1.5 mm/h (PMF: IL = 0 mm, CL = 1 mm/h)

6.3.5. Critical Storm Duration and Temporal Pattern Assessment

Critical storm duration refers to the duration of design storm that will result in the highest peak flood flows or levels at a particular location. The critical duration is influenced by various factors including upstream catchment area and may vary between locations of interest throughout a catchment or study area. With the introduction of ARR 2019, a representative temporal pattern must also be identified which produces a peak flow closest to but not less than the design peak flow (*that being the average of peak flows from an ensemble set of 10 temporal patterns*).

For the purposes of this study, definition of design flood conditions is required at various locations of interest which have varying catchment sizes and properties (*e.g., slope, degree of urbanisation, stream type and size etc.*), and therefore may have varying critical storm durations and applicable temporal rainfall patterns.

Given the run time of the developed TUFLOW two-dimensional hydraulic model, it is not practical to simulate multiple temporal patterns for multiple durations for each design flood (i.e., AEP). A more practical approach was thus adopted, as follows:

- The WBNM hydrologic model was used to determine critical storm durations, associated temporal patterns and average peak design flows at eight (8) key locations as shown in **Figure 6-2**.

- From this a number of critical storm durations and associated temporal patterns of interest were identified for further investigation for each flood magnitude.
- From the investigated storms, three durations were selected for each flood magnitude that in combination provided the overall best match to 'average peak design flows' across the assessment locations.

A summary of the selected critical storm durations and temporal patterns for each design event are presented in **Table 6-3**.

A comparison of peak design flood flows from the selected storm duration and temporal pattern combinations above with the average peak flow from the temporal pattern ensemble at each site are presented for the eight design events in **Appendix B**.

The resulting peak flood flows are generally comparable to the averaged peak flood flows, within a range of percentage difference that is typical of the ARR 2019 temporal pattern ensemble approach (i.e., 5% to 10%). However, selected peak flood flows for Parsons Gully and Middle Brook for some design events differ by more than 10% when compared to the averaged peak flow. The adoption of these flows for Parsons Gully and Middle Brook is considered immaterial given that the flows from Kingdon Ponds are much larger. As such, flooding along Kingdon Ponds is expected to result in peak flood conditions in the floodplain between Satur and Scone. The predicted flow rates for Parsons Gully, Middle Brook and Kingdon Ponds for the selected storm durations and temporal patterns were extracted from the WBNM hydrologic model and shown in **Table 6-4**Table 6-4.

Accordingly, it is considered that the selected storm durations and temporal patterns are the most suitable of those available to simulate an appropriate balance of peak design flood flows across all assessment locations. Therefore, the selected design rainfall hyetographs and parameters are appropriate for determining design flood hydrographs for the study catchments.

Table 6-3 Critical design storm durations and selected representative temporal patterns

Design Event	Selected critical storm durations and representative temporal pattens		
	Critical Duration (min)	Pattern Set	'Average' Pattern ID
20% AEP	360 min	East Coast (South) – frequent	Point – 4738
	540 min	East Coast (South) – frequent	Point – 4776
	1080 min	East Coast (South) – 200 km^2	Areal - 104
10% AEP	180 min	East Coast (South) - intermediate	Point – 4663
	360 min	East Coast (South) - intermediate	Point - 4726
	1080 min	East Coast (South) – 200 km^2	Areal - 104
5% AEP	120 min	East Coast (South) - intermediate	Point – 4628
	360 min	East Coast (South) - intermediate	Point – 4696
	1080 min	East Coast (South) – 200 km^2	Areal - 104
2% AEP	90 min	East Coast (South) - rare	Point – 4585
	360 min	East Coast (South) - rare	Point – 4694
	1080 min	East Coast (South) – 200 km^2	Areal - 104
1% AEP	90 min	East Coast (South) - rare	Point – 4585
	360 min	East Coast (South) - rare	Point – 4596
	1080 min	East Coast (South) – 200 km^2	Areal - 104
1 in 200 AEP	60 min	East Coast (South) - rare	Point – 4558
	180 min	East Coast (South) - rare	Point - 4651
	1080 min	East Coast (South) – 200 km^2	Areal - 104
1 in 500 AEP	60 min	East Coast (South) - rare	Point – 4558
	120 min	East Coast (South) - rare	Point - 4614
	1080 min	East Coast (South) – 200 km^2	Areal - 104
PMF	30 min	Temporal Pattern from Table 1 of '*The Estimation of Probable Maximum Precipitation in Australia: Generalised Short Duration Method*' (BoM, 2003)	
	90 min		
	180 min		

Table 6-4 Comparison of Peak Flow Rates for Selected Storm Events

Design Event	WBNM Peak Flow at Liverpool St (m^3/s)		
	Parsons Gully	Middle Brook	Kingdon Ponds
20% AEP	56.3	80.2	191.6
10% AEP	80.6	101.5	255.1
5% AEP	106.8	135.4	316.8
2% AEP	147.5	173.7	401.2
1% AEP	142.9	225.0	466.0
1 in 200 AEP	201.5	207.3	527.4
1 in 500 AEP	266.1	227.8	614.5
PMF	1828.0	2508.6	6620.2

6.4. Blockage of Drainage Structures

Design flood modelling for existing conditions has adopted bridge and culvert blockage factors that align with the guidelines documented in Australian Rainfall and Runoff 2019 (ARR 2019) Book 6 Chapter 6 '*Blockage of Hydraulic Structures*'. The design blockage factors are summarised in **Table 6-5**.

It is noted that the available guidance in ARR 2019 does not specifically address design blockage factors for urban stormwater drainage networks. The design blockage factors for the stormwater network at Scone has been adopted following discussions with Council and DPE staff.

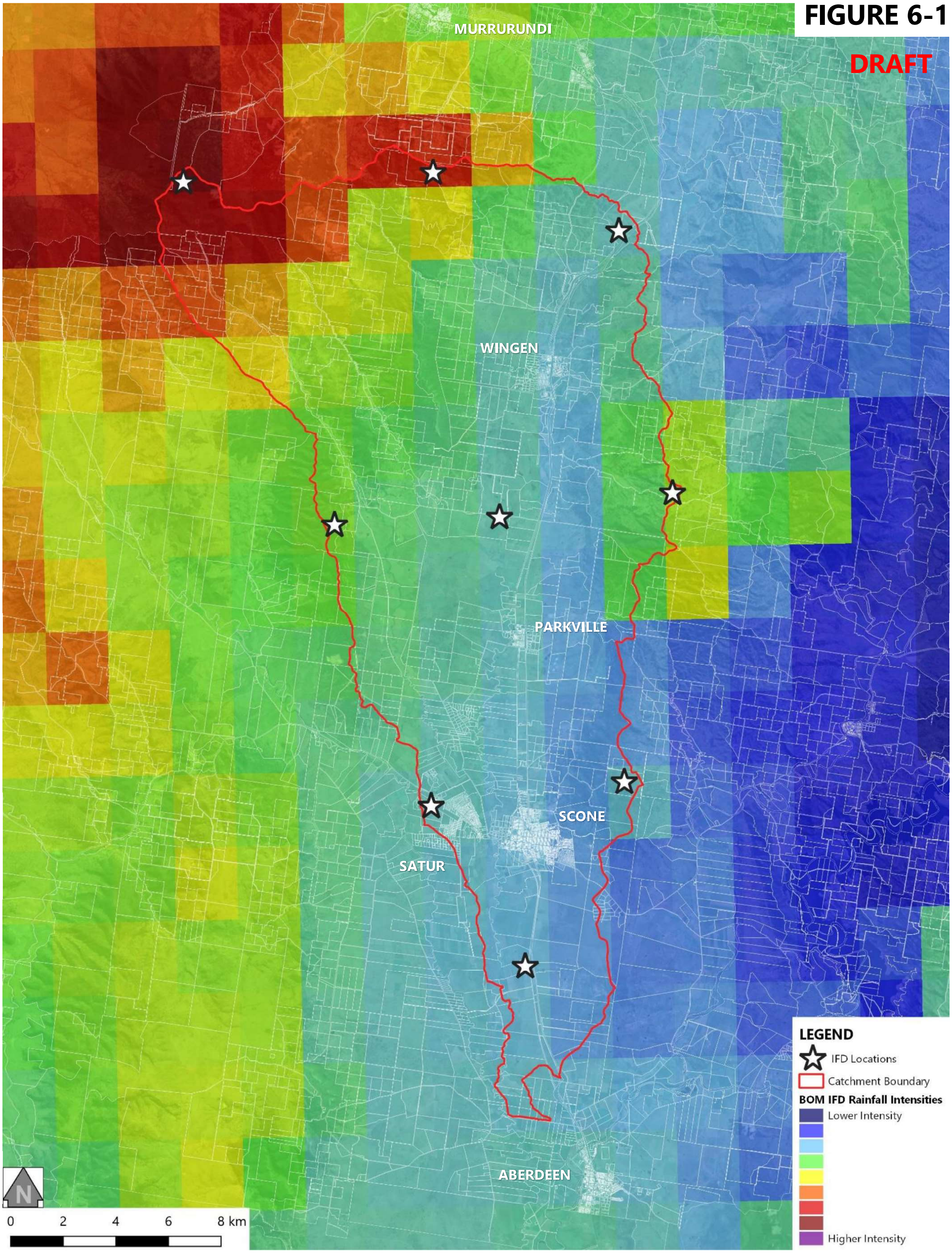
Table 6-5 Summary of Design Blockage Factors

Drainage Structure	Design Blockage Factor
Figtree Gully bridges and culverts (opening width < 1.5 m)	More frequent than 5% AEP - 25% Between 5% AEP and 0.5% AEP - 50% Rarer than 0.5% AEP - 100%
Figtree Gully bridges and culverts (opening width ≥ 1.5 m)	More frequent than 5% AEP - 0% Between 5% AEP and 0.5% AEP - 10% Rarer than 0.5% AEP - 20%
Kingdon Ponds and Middle Brook bridges over Liverpool St	More frequent than 5% AEP - 0% Between 5% AEP and 0.5% AEP - 0% Rarer than 0.5% AEP - 10%
Parsons Gully culverts through Liverpool St	More frequent than 5% AEP - 0% Between 5% AEP and 0.5% AEP - 15% Rarer than 0.5% AEP - 25%

Drainage Structure	Design Blockage Factor
Stormwater Drainage Network (diameter < 0.6 m)	More frequent than 5% AEP - 25% Between 5% AEP and 0.5% AEP - 50% Rarer than 0.5% AEP - 100%
Stormwater Drainage Network (diameter ≥ 0.6 m)	More frequent than 5% AEP - 0% Between 5% AEP and 0.5% AEP - 25% Rarer than 0.5% AEP - 50%

FIGURE 6-1

DRAFT



Prepared by:

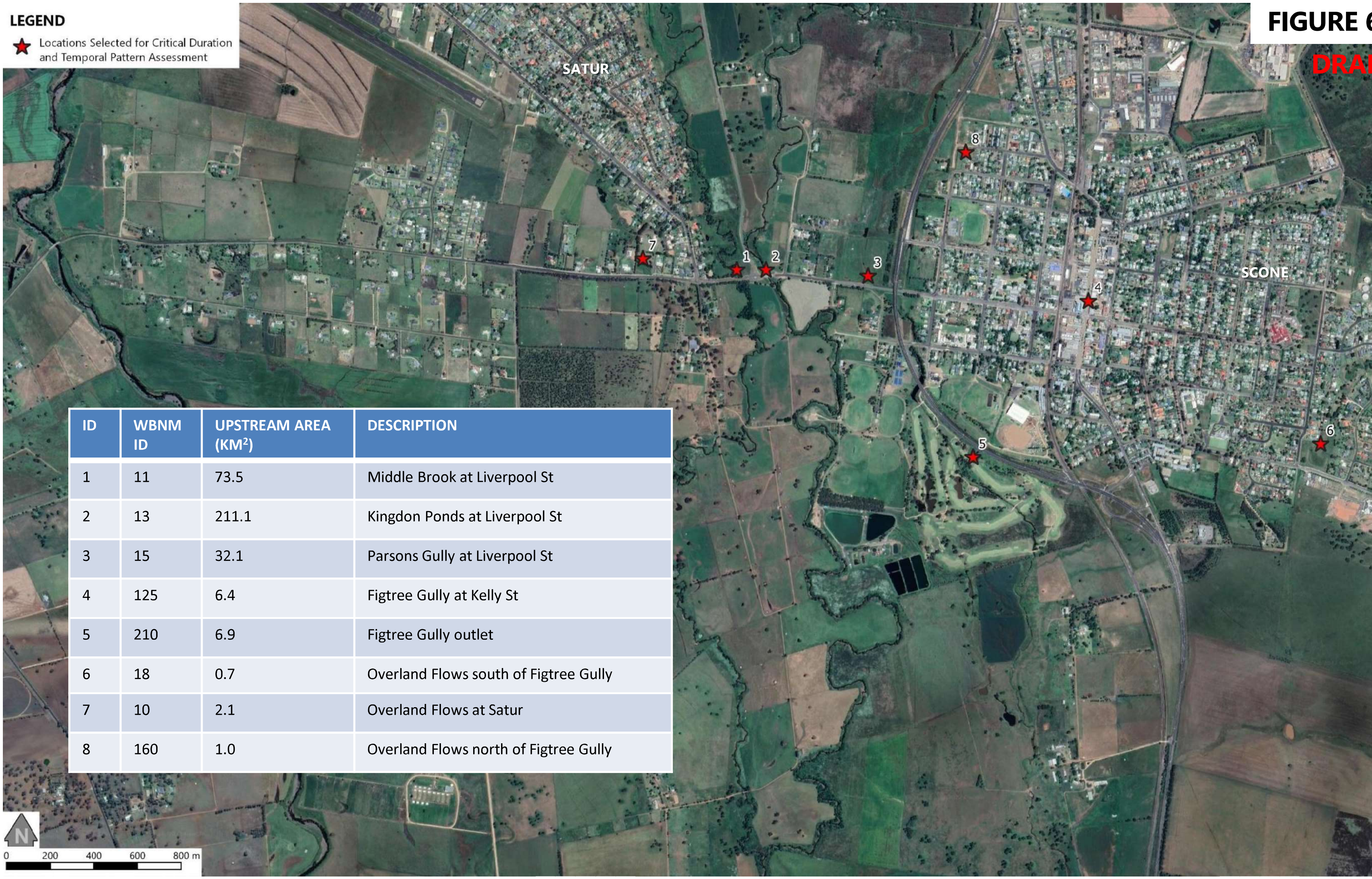
211019_Scone_TUFLOW.qgs

fg311015-00018_220304_ReportFigs_A4P.pdf

ADOPTED IFD LOCATIONS

FIGURE 6-2

DRAFT



ID	WBNM ID	UPSTREAM AREA (KM²)	DESCRIPTION
1	11	73.5	Middle Brook at Liverpool St
2	13	211.1	Kingdon Ponds at Liverpool St
3	15	32.1	Parsons Gully at Liverpool St
4	125	6.4	Figtree Gully at Kelly St
5	210	6.9	Figtree Gully outlet
6	18	0.7	Overland Flows south of Figtree Gully
7	10	2.1	Overland Flows at Satur
8	160	1.0	Overland Flows north of Figtree Gully

UPPER HUNTER SHIRE COUNCIL

Prepared by: worley consulting

LOCATIONS SELECTED FOR CRITICAL DURATION AND TEMPORAL PATTERN ASSESSMENT

7. Design Flood Results

7.1. Design Flood Mapping

Design flood mapping for Scenario ID 2: Existing Conditions is presented in **Figure 2-1** to **Figure 2-96** of **Volume 2** of this report. This includes peak flood depth, level and velocity maps for the 20%, 10%, 5%, 2%, 1%, 1 in 200 and 1 in 500 AEP design events as well as the PMF.

The flood mapping presented in Volume 2 of this report comprises of peak flood conditions produced by a process known as 'flood enveloping'. For each design flood event and parameter (i.e. depth, level, velocity and hazard) this process combines maximum flood model results from the three selected duration / temporal pattern combinations (refer **Table 6-3**) to produce a 'design flood envelope'.

In order to properly define flooding along minor tributaries and overland flowpaths, this study adopted a hydrologic method where local runoff hydrographs were applied to the TUFLOW hydraulic model at a fine spatial resolution. Consequently, model results required filtering to distinguish 'flooding' from areas of shallow catchment runoff and minor ponding.

The filtering criteria applied to the peak design flood envelopes prior to mapping are described in in the following:

- Depth ≥ 0.15 m
  - This criterion removes flood depths shallower than 0.15 m which are generally considered quite benign
- Velocity x Depth ≥ 0.025 m^2/s
  - This criterion was used to include depths shallower than 0.15 m where some flow conveyance is evident which may:
    - Occur near-bank along creeks and waterways
    - Form part of overland flood flow paths
    - Form important linkages between deeper areas of flooding and their source
  - Mapping of these shallower flows can be important as:
    - It provides a better understanding of flood behaviour
    - Obstruction of such flows may have adverse flood impacts
    - It provides confidence that discrete 'ponds' of inundation removed by the following mapping criterion are not associated with broader flood flowpaths
- Area of inundation ≥ 100 m^2

This criterion removes discrete areas of inundation with an area of less than 100 m^2. Such areas are generally expected to be related to local ponding in ground depressions rather than significant flood flowpaths.

7.2. General Description of Flood Behaviour

A description of the TUFLOW model results is provided in the following for key locations in the study area.

7.2.1. Scone – Figtree Gully

Figtree Gully enters the Scone township near the intersection of Barton Street and Susan Street at the eastern edge of the town. Floodwaters are conveyed along an open grassed channel between Barton Street and Park Street. Figtree Gully then transitions into a concrete channel downstream of Park Street, passing through the Scone Central Business District (CBD) from the north-east to the south-west. The watercourse transitions back into a natural channel downstream of Guernsey Street and flows in a southerly direction through White Park before discharging into Parsons Gully to the south of the Scone Bypass.

The hydraulic model results indicate that the Figtree Gully channel in the urban areas of Scone has a limited flow conveyance, with some flow breakouts occurring at several locations in the 20% AEP event. These locations include areas near Waverley Street and Main Street, as well as immediately downstream (west) of the Scone RSL club as the watercourse transitions back into a natural channel. Once the capacity of the channel is exceeded, floodwaters are expected to route overland to the south and west through several residential lots and along road reserves.

Within the Scone CBD, the hydraulic model results indicate that areas along Kelly Street to the south of the Liverpool Street intersection are the most flood prone, with inundation expected in events as frequent as the 20% AEP storm. Some areas of Kelly Street between Liverpool Street and St Aubins Street are also inundated during the 20% AEP event, but to a lesser degree.

During the 1% AEP event, areas of high flood hazard that may pose a significant threat to life and property (e.g. ≥ H4 Hazard) are confined within the Figtree Gully channel. Inundated areas outside of the Figtree Gully channel are typically classified as H1 to H2 Hazard, with some localised areas of H3 Hazard resulting from flood depths in excess of 0.5 metres. The flood hazard categorisation is discussed in further detail in **Section 8.1**.

During the PMF event, the extent and degree of hazard posed to life and property would increase significantly. Large portions of commercial and residential areas in Scone would be inundated with the flood hazard typically ranging from H3 to H5.

The critical storm duration for the range of design events for Figtree Gully is shown in **Table 7-1**.

Table 7-1 Summary of Critical Storm Durations along Figtree Gully

Design Event	Critical Duration
20% AEP	9 hours
10% AEP	6 hours
5% AEP	6 hours
2% AEP	6 hours
1% AEP	6 hours

Design Event	Critical Duration
1 in 200 AEP	3 hours
1 in 500 AEP	2 hours
PMF	1.5 hours

7.2.2. Satur

The satellite township of Satur is separated from Scone by Middle Brook, Kingdon Ponds and Parsons Gully. Properties along the eastern edge of Satur are located adjacent to Middle Brook, which flows in a north to south direction past the town. These properties are elevated at least 5 metres above the Middle Brook floodplain. The flood model results indicate that the majority of these properties are not expected to be inundated by flooding of Middle Brook in events up to and including the PMF. During the PMF, floodwaters from Middle Brook may inundate the eastern portions of some properties but are not expected to inundate any existing houses.

However, it is noted that there is an overland flow path which originates near the Scone TAFE and generally travels from north-west to south-east in the vicinity of Satur. This overland flow path is predicted to inundate Gray Street, Gunsynd Close, Satur Road and a number of nearby properties during the 20% AEP event.

During the 1% AEP event, the flood hazard in the vicinity of Satur is typically categorised as H1, with some localised areas categorised as H2.

At the peak of the PMF, this overland flow path is expected to inundate a large portion of Satur near the north-western corner of the township. The flood hazard category typically ranges between H2 and H3 in residential lots, increasing to H4 and H5 along sections of Gray St and Satur Road.

7.2.3. Middle Brook, Kingdon Ponds and Parsons Gully Floodplain

The three major watercourses of Middle Brook, Kingdon Ponds and Parsons Gully flow past Scone and Satur from north to south, passing beneath Liverpool Street in the immediate vicinity of the towns. These watercourses share a common floodplain near Scone, which is typically characterised by undeveloped pastureland with a small number of buildings and private properties.

The Kingdon Ponds channel has a limited flow conveyance property in areas downstream (south) of Parkville. This results in flows breaking out of the Kingdon Ponds channel in events as frequent as the 20% AEP event. These breakout flows discharge into the adjacent watercourses of Parsons Gully and Middle Brook at several locations between Parkville and Scone. Subsequently, a significant portion of the flows along Parsons Gully and Middle Brook arriving at the Liverpool Street crossing is expected to have originated from floodwaters escaping the Kingdon Ponds channel further upstream (north).

The breakout of flows from Kingdon Ponds was also identified and discussed during the model calibration and verification process (refer **Section 5.4.4**).

The flood model results indicate that a number of properties on the common floodplain between Scone and Satur are predicted to be inundated in events as frequent as the 20% AEP event. In particular, this includes properties in the vicinity of Morse Street and Wingen Street, as well as the properties on the western side of Aberdeen Street to the south of Liverpool Street.

During the 1% AEP event, the majority of the common floodplain between Scone and Satur is inundated to depths exceeding 0.5 metres. The flood hazard is also typically H3 or higher in the vicinity of Liverpool Street. The majority of properties in the floodplain are expected to be inundated, as well as the entirety of the Bill Rose Sports complex and the Scone Golf Club.

During the PMF event, floodwaters from the three watercourses form a continuous body of water between Satur and Scone, with high flood depths and flow velocities resulting in a flood hazard category of H6 throughout most of the common floodplain.

7.3. Design Flood Hydrographs

Design flood hydrographs simulated using the WBNM hydrologic model are presented in **Appendix B** for the following key locations:

- Figtree Gully at Kelly Street in the Scone Central Business District;
- Parsons Gully at Liverpool Street;
- Middle Brook at Liverpool Street; and
- Kingdon Ponds at Liverpool Street.

7.4. Tabulated Hydraulic Model Results

Peak design flood results from the TUFLOW hydraulic model are presented in **Appendix C** for the following key locations:

- Barton Street crossing of Figtree Gully;
- Oxford Road crossing of Figtree Gully;
- Waverley Street crossing of Figtree Gully;
- Park Street crossing of Figtree Gully;
- Intersection of Main Street and St Aubins Street near Figtree Gully;
- Intersection of Liverpool Street and Kelly Street in the Scone CBD;
- Kelly Street near Commonwealth Bank in the Scone CBD;
- Kingdon Street crossing of Figtree Gully;
- Parsons Gully crossing of Kingdon Street;
- Residential lots on the western side of Aberdeen Street south of Liverpool Street;
- Lots on floodplain north of Liverpool Street (near Morse Street); and
- Lots on floodplain south of Liverpool Street (near Wingen Street).

7.5. Inundation of Major Roads

Flood model results indicate that various major roads in the study area would be inundated in flood events as frequent as the 20% AEP. Simulated flood depth and duration information for design blockage factors at a number of key locations is presented in **Table 7-2** for the full range of design floods investigated. The reporting locations are indicated in **Figure 7-1** along with the frequency of design flood in which each location would be expected to become unsafe for vehicular passage.

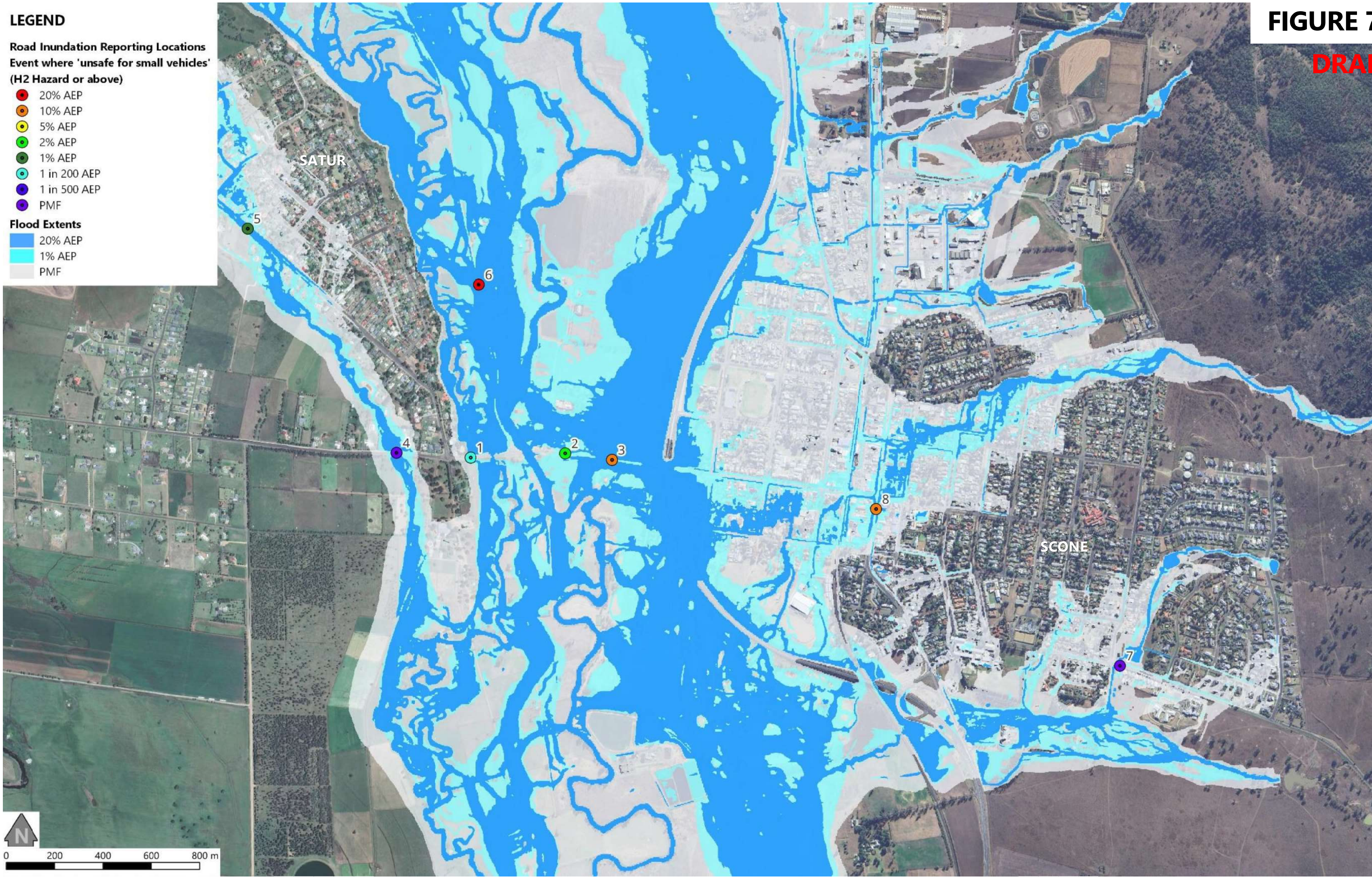
It is noted that not all locations that major roads become inundated have been reported, but that those locations where the earliest or most severe inundation is expected are generally included. For example, inundation of Middlebrook Road may occur near Scone Race Club as well as adjacent to Satur. However, flooding is more frequent and severe at the location adjacent to Satur and hence this reporting location was selected. Similarly, road low points adjacent to bridges are often overtopped prior to the bridges themselves and these have been reported on.

The information presented in **Table 7-2** and **Figure 7-1** is summarised in the following:

- Liverpool Street would be expected to be overtopped to depths of about 0.12 metres during the 20% AEP event.
- In the 10% AEP event, Liverpool Street is overtopped at several locations by flows from Middle Brook, Kingdon Ponds and Parsons Gully for a duration of between 3.5 and 4.5 hours. The peak depth of inundation during the 10% AEP event is about 0.39 metres.
- Moobi Road and Satur Road are inundated to depths of 0.15 metres or less in events up to and including the 1% AEP event.
- Middlebrook Road is expected to be overtopped at several locations during the 20% AEP event. The peak depth of inundation during the 20% AEP event is about 0.30 metres, with a duration of inundation of about 3 hours.
- Within the Scone CBD, Kelly Street is expected to be inundated by flows escaping from Figtree Gully in events as frequent as the 20% AEP. The section of Kelly Street to the south of the Liverpool Street intersection is particularly flood-prone, with flood depths reaching about 0.28 metres in the 20% AEP event.

FIGURE 7-1

DRAFT



Prepared by: worley consulting

UPPER HUNTER SHIRE COUNCIL

INUNDATION OF MAJOR ROADS

Table 7-2 Major Road Inundation Depth and Duration Information

ID	Road	Watercourse	Location	Road Elevation (mAHD)	20% AEP		10% AEP		5% AEP		2% AEP	
					Peak Depth (m)	Duration (hrs)	Peak Depth (m)	Duration (hrs)	Peak Depth (m)	Duration (hrs)	Peak Depth (m)	Duration (hrs)
1	Liverpool St	Middle Brook	Low point 90 metres west of watercourse crossing	203.47	0.08	3.25	0.11	4.50	0.15	5.50	0.17	6.50
2	Liverpool St	Kingdon Ponds	Low point 160 metres east of watercourse crossing	201.87	N/A	N/A	0.06	3.25	0.09	4.50	0.21	5.50
3	Liverpool St	Parsons Gully	Low point 120 metres west of watercourse crossing	201.18	0.12	2.00	0.39	3.50	0.60	4.50	0.80	5.50
4	Moobi Road	Middle Brook Tributary	210 metres west of Satur Rd intersection	204.57	N/A	N/A	N/A	N/A	0.08	2.50	0.11	3.25
5	Satur Road	Middle Brook Tributary	75 metres south-east of Seaward Ave intersection	215.53	0.07	12.75	0.08	13.25	0.11	13.00	0.15	13.50
6	Middlebrook Road	Middle Brook	700 metres north of Liverpool Street	204.35	0.30	3.25	0.42	4.50	0.50	5.50	0.55	6.75
7	Gundy Road	Unnamed Flowpath	Near Gundy Road / Barton Street intersection	211.90	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
8	Kelly Street	Figtree Gully	50 metres south of Liverpool Street (outside Commonwealth Bank)	211.32	0.28	2.75	0.41	3.25	0.56	4.75	0.66	5.25

ID	Road	Watercourse	Location	Road Elevation (mAHD)	1% AEP		1 in 200 AEP		1 in 500 AEP		PMF	
					Peak Depth (m)	Duration (hrs)	Peak Depth (m)	Duration (hrs)	Peak Depth (m)	Duration (hrs)	Peak Depth (m)	Duration (hrs)
1	Liverpool St	Middle Brook	Low point 90 metres west of watercourse crossing	203.47	0.23	7.00	0.26	7.50	0.30	8.00	2.61	10.75
2	Liverpool St	Kingdon Ponds	Low point 160 metres east of watercourse crossing	201.87	0.38	6.25	0.55	6.75	0.74	7.25	4.50	10.75
3	Liverpool St	Parsons Gully	Low point 120 metres west of watercourse crossing	201.18	0.97	6.25	1.14	6.75	1.33	7.50	5.37	11.00
4	Moobi Road	Middle Brook Tributary	210 metres west of Satur Rd intersection	204.57	0.13	3.50	0.15	2.00	0.21	3.25	0.72	9.75
5	Satur Road	Middle Brook Tributary	75 metres south-east of Seaward Ave intersection	215.53	0.15	9.25	0.18	11.25	0.22	11.50	0.55	10.00
6	Middlebrook Road	Middle Brook	700 metres north of Liverpool Street	204.35	0.67	7.75	0.74	8.25	0.80	8.75	3.44	10.50
7	Gundy Road	Unnamed Flowpath	Near Gundy Road / Barton Street intersection	211.90	N/A	N/A	0.05	3.00	0.08	11.25	0.34	7.75
8	Kelly Street	Figtree Gully	50 metres south of Liverpool Street (outside Commonwealth Bank)	211.32	0.68	5.50	0.78	4.50	0.89	11.50	2.25	9.75

Notes:

1. Road elevation and depth extracted from TUFLOW model at a single point
2. Durations of inundation are estimated to the nearest 15 minutes from TUFLOW model results for the 'critical storm duration' only. Shallow inundation caused by local stormwater flows has generally been excluded from these estimations.

8. Flood Hazard, Flood Function and Emergency Response Classification

8.1. Provisional Flood Hazard

Flood hazard provides a measure of the potential risk to life, well-being and property posed by a flood. ARR 2019 presents a set of hazard curves which assess the vulnerability of people, vehicles and buildings to flooding based on the velocity and depth of flood flows. These curves have been adopted to define flood hazard in this study and are reproduced in **Figure 8-1**.

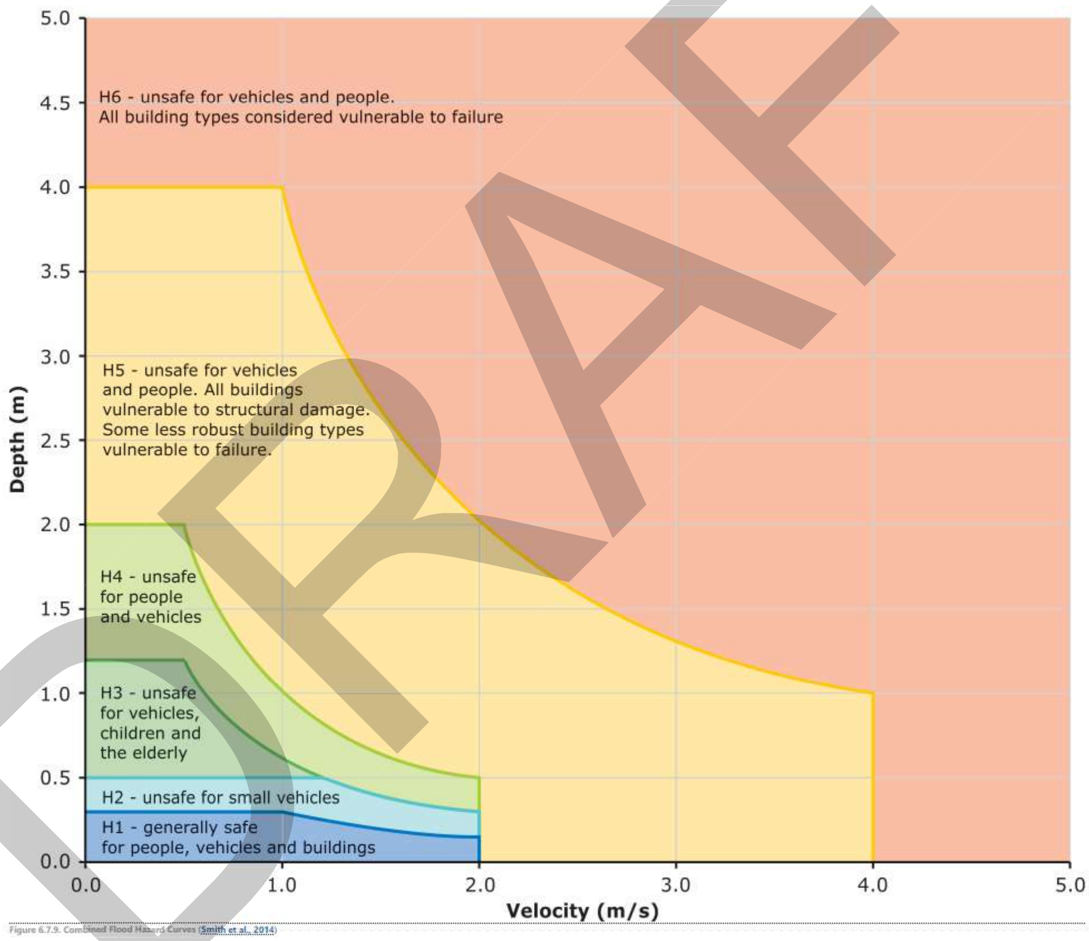


Figure 8-1 ARR 2019 Flood Hazard Curves

Provisional Flood Hazard maps for the 5% AEP, 1% AEP and PMF events under existing catchment conditions with the design blockage factors are presented in **Figure 8-1** to **Figure 8-12** in Volume 2 of this report.

The presented hazards are considered ‘provisional’ as they do not consider additional factors which may contribute to flood hazard including: rate of rise of floodwaters; effective warning time; flood preparedness; duration of flooding; evacuation problems; effective flood access; and type of development. Such factors should be considered as part of a future Floodplain Risk Management Study to determine true flood hazard.

8.2. Flood Function

The delineation of the floodplain into "flood function" or "hydraulic categories" based on its function during floods is used as a tool to help inform what impact development activity within the floodplain may have on flood behaviour.

The *Flood Risk Management Manual* (DPE, 2023) defines three hydraulic categories based on flood functions as described below:

- **Floodway areas** are those areas of the floodplain which generally convey a significant discharge of water during floods and are sensitive to changes that impact flow conveyance. They often align with naturally defined channels or form elsewhere in the floodplain. Even their partial blockage would cause a significant redistribution of flood flow or a significant increase in flood level.
- **Flood storage areas** are those areas of the floodplain that are outside floodways which generally provide for temporary storage of floodwaters during the passage of a flood and where flood behaviour is sensitive to changes that impact on temporary storage of water during a flood. Loss of flood storage can increase the severity of flood impacts by reducing natural flood attenuation.
- **Flood fringe areas** are the remaining area of the floodplain after floodway and flood storage areas have been defined. Development in flood fringe areas would not have any significant effect on the pattern of flood flows and/or flood levels.

The resulting flood function mapping is presented in **Figure 9-1** to **Figure 9-12** in Volume 2 of this report for the 5% AEP, 1% AEP and PMF design flood events.

8.2.1. Definition of Floodway Areas

There is no specific procedure for defining the extent of the floodway and it has been well established that there is no uniform criteria that can be applied across the wide range of floodplain types and flood behaviour encountered (*e.g. Howells et al., 2003*). The *Floodplain Risk Management Guideline FB02: Flood Function* (DPE, 2023) defines floodways as areas which convey a high proportion of flood flows. This guideline also specifies that floodways should be connected, continuous and hydraulically logical.

Typically, the floodway is defined for the design planning level flood, in this case the 1% AEP design event, but may also take into consideration the variation in flood behaviour across a range of flood severities. For the purposes of this study, the floodway extent has been derived as described in the methodology below in consideration of procedures outlined by Thomas and Golaszewski (2012 and 2018) and Howells et al (2003).

1% AEP Floodway Areas

- **Kingdon Ponds, Parsons Gully and Middle Brook**
  - VxD thresholds representing the '80% flow' width were investigated at several key cross-sectional locations.
  - Results were predominantly between 0.6 m^2/s and 1.0 m^2/s.
  - The mapped extents of this range of VxD thresholds were reviewed to determine an appropriate VxD to indicate the floodway extent.
    - The floodplain is complex with multiple channels and flood runners / secondary flowpaths.
    - Using VxD thresholds at the higher end of the indicative 80% flow range (e.g. 0.8 to 1.0 m^2/s) important secondary flowpaths were often not identified or exhibited a poor level of continuity that would not be appropriate for floodway mapping.
    - A VxD threshold of 0.6 m^2/s considerably improved the identification of secondary flowpaths and continuity.
    - However, it was considered appropriate to adopt a lower threshold of 0.5 m^2/s. This further improved continuity while generally resulting in only a small lateral increase in the floodway area (typically less than 10 metres).
  - After applying the VxD threshold of 0.5 m^2/s several manual edits were made to improve continuity along secondary flowpaths using lower VxD values as a guide. Remaining smaller discontinuous areas were filtered out.
  - The selected VxD threshold of 0.5 m^2/s represents about 85 to 90% of the flow conveyance across the key cross-sectional locations analysed. According to *Flood Risk Management Guideline FB02: Flood Function* (DPE 2023), this remains within the expected range of flow conveyance (80 to 90%) where blockage outside of these areas would not be expected to result in an increase in water level of 100 mm or more.
  - Accordingly, the selected VxD threshold of 0.5 m^2/s is considered appropriate for the floodplains of Middle Brook, Kingdon Ponds and Parsons Gully.
- **Figtree Gully, minor tributaries and overland flowpaths**
  - A similar approach to that described above was adopted.
  - VxD thresholds representing the '80% flow' width were investigated at several key cross-sectional locations.
  - Results were predominantly between 0.2 m^2/s and 0.3 m^2/s.
  - It was considered appropriate to adopt a threshold of 0.25 m^2/s.
  - After applying the VxD threshold of 0.25 m^2/s several manual edits were made to improve continuity along flowpaths using lower VxD values as a guide. Remaining small discontinuous areas were filtered out.

5% AEP Floodway Areas

- The same VxD indicator values were adopted as the 1% AEP event with manual edits made to improve continuity.
- While slightly lower thresholds could have been considered, the adopted criteria resulted in a suitably continuous floodway, and floodway and storage extents that were suitably narrower than those for the 1% AEP. Adoption of lower indicator values may have resulted in extents similar to or larger than those for the 1% AEP, which would not be expected.

PMF Floodway Areas

- The following VxD floodway indicator values were adopted following an investigation of the '80% flow' width at several key locations in the study area:
  - Kingdon Ponds and Parsons Gully: 6 m^2/s, generally representing about 75 to 90% of flow conveyance.
  - Middle Brook: 3 m^2/s, generally representing about 70 to 90% of flows.
  - Figtree Gully & minor tributaries/flowpaths: 1 m^2/s, generally representing about 70 to 90% of flows.
- The above criteria alone result in significant discontinuities in the floodway, even in locations where the 1% AEP floodway is continuous. In particular this is evident along the Kingdon Ponds watercourse, which shows that Parsons Gully becomes the main flow conveyance path in this event rather than Kingdon Ponds.
- The 1% AEP floodway was adopted in areas of discontinuity.
- Further manual edits were made to improve continuity using lower VxD values as a guide.

8.2.2. Definition of Flood Storage Areas

1% and 5% AEP Flood Storage Areas

- Depth has been used as indicator to determine the location and extent of flood storage areas.
- In past studies, Worley Consulting has adopted peak depths of 0.3 m or 0.5 m to indicate flood storage areas, while others have adopted 1.0 m in various studies.
- The intention of identifying flood storage is to avoid the filling/development of areas which would result in adverse flood level impacts due to loss of temporary flood storage.
- The most common method of identifying flood storage areas is using a peak depth indicator. It is noted that this alone cannot determine whether filling would cause flood level impacts, however, it does highlight the need to investigate the flood impacts of potential developments in affected areas including any associated loss of storage.
- An indicator depth of 0.5m appears appropriate for the study area for the 5% and 1% AEP events. A lower depth criterion of 0.3 m (for example) is likely to unduly constrain development, while a higher depth criterion of 1.0 m (for example) is likely to be too liberal.

PMF Flood Storage Areas

- Based on a review of the design flood results, almost the entire floodplain between Satur and Scone has peak depths of greater than 0.5 metres. Therefore, a higher depth criteria would be suitable to define flood storage areas for the PMF.
- An indicator depth of 1 metre was adopted to define flood storage areas for the PMF.

8.3. Flood Emergency Response Planning Classification

The flood emergency response planning classification provides an indication of the relative vulnerability of communities in flood emergency response situations and helps to identify the type and scale of information needed by the SES to assist with emergency response planning.

Guidance on the classification process is provided in *Floodplain Risk Management Guideline: Flood Emergency Response Planning Classification of Communities* (OEH and SES 2007) and *Australian Disaster Resilience Guideline 7-2 Flood Emergency Response Classification of the Floodplain* (AIDR 2017).

More recently, the classification process was also included in *Support for Emergency Management Planning – Flood Risk Management Guide EM01* (DPE 2022). These documents describe similar methodologies for emergency response classification, however employ different terminology.

Terminology per the DPE (2022) guideline has been adopted in this study, with flood emergency response planning classifications as follows:

- **Flood Islands:** These areas can be linked to areas outside of the floodplain by roads. These roads can be cut by floodwater, closing all the evacuation routes and creating an island. After closure of the roads, access to the area is by boat or aircraft. It is assumed that vehicle or pedestrian evacuation is <u>not</u> practical before the evacuation route is inundated. Flood islands are classified according to what can happen after the evacuation route is cut, as follows.
  - **Low Flood Island**: During a flood event the area is first surrounded and isolated by floodwater and will then be inundated if floodwater continues to rise.
  - **Low Trapped Perimeter Area**: During a flood event, practical evacuation routes are first inundated isolating land that will then be inundated if floodwater continues to rise. These would generally be areas at the fringe of the floodplain where the only practical road or overland access is through flood prone land.
  - **High Flood Island**: During a flood event the area is surrounded and isolated by floodwater, but enough flood-free land remains to cope with the number of people in the area.
  - **High Trapped Perimeter Area**: During a flood event, practical evacuation routes are inundated isolating land that remains flood-free and can cope with the number of people in the area. These would generally be areas at the fringe of the floodplain where the only practical road or overland access is through flood prone land.
- **Areas with rising access out of the floodplain:** These are inhabited areas where vehicle or pedestrian evacuation <u>is</u> practical before the evacuation route is inundated. Evacuation access is available to an area of safety with adequate services and accommodation available.
  - **Overland Escape**: During a flood event, access roads are inundated but flood-free land can be reached by walking overland to escape rising floodwater.
  - **Rising Road Access**: Areas where access roads rise steadily uphill and away from rising floodwater.
- **Indirectly affected areas:** These are areas outside of the limit of flooding which would not lose road access and also would not be inundated. However, these areas may be indirectly affected as a result of flood-damaged infrastructure or due to the loss of transport links, electricity supply, water supply, sewage or telecommunications services. These areas may therefore require resupply or in the worst case, evacuation.
- **Overland refuge areas:** These are areas that the community in other areas of the floodplain may be evacuated to temporarily where there is adequate warning and response time, but which are isolated from the edge of the floodplain by floodwaters.

Flood emergency response classification mapping has been prepared for the 5%, 1% and 1 in 500 AEP events as well as the PMF and is presented in **Figure 11-1** to **Figure 11-12** in Volume 2 of this report.

The following is noted about the method employed:

- Classifications were assigned based on analysis of the sequence in which flooding of access routes and properties occurs.
- Due to the numerous overland flow paths in the study area, the classification was generally completed on block by block basis rather than at a broader precinct scale.
- It was assumed that there would be no warning time available along Figtree Gully and other overland flow paths due to the fast response time in these catchments. Therefore, it was generally assumed that evacuation is not practical prior to the inundation of these areas.
- However, evacuation the Figtree Gully and other overland flow catchments were considered possible and practical if the flood hazard within the inundated block and its access roads were classified as H1 or H2. Based on the ARR 2019 flood hazard curves (refer **Figure 8-1**), it was considered possible for residents to safely evacuate such areas even at the peak of the flood.
- With the exception of the PMF, it was assumed that there would be sufficient warning time available for properties which would be inundated by the flooding of Kingdon Ponds and Parsons Gully due to the longer response time of the catchment. Therefore, it was assumed that evacuation is practical prior to the inundation of these areas.
- In many 'low trapped perimeter areas' overland evacuation may be possible by less practical routes such as by climbing over fences.

Overland refuge areas were not mapped as they were assumed to be functionally similar to High Flood Islands or High Trapped Perimeter areas.

9. Assessment of the Potential Impacts of Climate Change

9.1. Climate Change and Flooding

The Intergovernmental Panel on Climate Change's *Fifth Assessment Report* (IPCC 2013) found that human influence on climate is clear and increasing, with impacts observed across all continents and oceans. While projections vary, there is a general consensus that climate change will alter the severity of flood impacts through sea level rise (SLR) and an increase in the intensity of heavy rainfall events.

Quantifying the potential impacts of climate change on flooding allows current decisions on proposed development and flood risk mitigation measures within the study area to be assessed in an informed manner that considers potential changes in flood risk in the future.

Sea Level Rise

Elevations within the Scone catchment are in excess of 180 mAHD. Accordingly, the impact of sea level rise is not expected to influence flood behaviour in the study area.

Increase in Rainfall Intensity

While climate models show uncertainty in quantifying the effect of climate change on rainfall intensity, the latest *Climate Change in Australia Technical Report* from CSIRO and BoM (2015) projects increased intensity of extreme rainfall events for the east coast with a high confidence.

Scenarios of between 10% and 30% increases are recommended in *Practical Consideration of Climate Change* (DECC, 2007) remain comparable to ranges projected by more recent research (e.g. CSIRO and BoM, 2015) and are appropriate for providing an assessment of the range of potential impacts.

For the purposes of this study, the potential impacts of increased rainfall intensity associated with climate change have been assessed by comparing model results for the 1% AEP design flood with those for the 1 in 200 AEP (about a 15% increase in rainfall) and 1 in 500 AEP (about a 35% increase in rainfall) events. Relevant model results are presented in the following.

9.2. Summary of Potential Climate Change Impacts

9.2.1. Impact of a 15% Increase in Rainfall Intensity on the 1% AEP Event

The impact of a 15% increase in rainfall intensity on modelled peak flood levels for the 1% AEP event are presented in Volume 2 of this report. The findings are summarised as follows.

- Peak flood levels typically increased by between 0.05 and 0.1 metres along most tributaries, with an increase of 0.2 metres predicted in some areas (notably in the vicinity of Liverpool Street between Scone and Satur).
- Peak flood levels increased by between 0.3 and 0.5 metres in some localised areas immediately upstream (east) of the Scone Bypass.

9.2.2. Impact of a 35% Increase in Rainfall Intensity on the 1% AEP Event

The impact of a 35% increase in rainfall intensity on modelled peak flood levels for the 1% AEP event are presented in Volume 2 of this report. The findings are summarised as follows.

- Peak flood levels typically increased by between 0.1 and 0.2 metres along most tributaries, with an increase of about 0.4 metres predicted in the vicinity of Liverpool Street between Scone and Satur.
- Peak flood levels increased by about 0.95 metres in a localised area immediately upstream (east) of the Scone Bypass near the railway overpass.

10. Sensitivity Analysis

Difference mapping was prepared to quantify the impact of variations in flood model parameters on design flood levels. The difference maps show changes in peak flood level estimates from the results of model simulations undertaken for 'design' and 'sensitivity' scenarios. As indicated by the legend the flood maps, increases in peak flood level are represented by shades of yellow to red and decreases are represented by shades of blue. The white shading indicates changes in peak flood level that are between +/- 0.05 metres.

10.1. Sensitivity to Model Downstream Boundary Condition

A normal-depth downstream boundary condition was adopted at the southern extent of the model. A gradient of 0.5% was adopted for design flood modelling based on the topography in the vicinity of the downstream model boundary.

The sensitivity of 5% and 1% AEP event peak flood levels to a variation in the downstream boundary condition was tested by adopting a flatter gradient of 0.1%. The impacts of this change in downstream boundary condition are presented in Volume 2 of this report.

The mapping shows that the adoption of a flatter downstream boundary condition does not lead to any notable changes in peak flood levels in the vicinity of Scone or Satur for both the 5% and 1% AEP events. The peak flood level is predicted to increase only in the immediate vicinity of the downstream boundary condition.

10.2. Sensitivity to Blockage Factors

The sensitivity of 5% and 1% AEP peak flood levels to the blockage of hydraulic structures and the stormwater network has been tested by applying increased and decreased blockage factors. The blockage factors tested for this sensitivity analysis are summarised in **Table 10-1** below.

The impacts of increased and decreased blockage factors on modelled peak flood levels for the 5% and 1% AEP event are presented in Volume 2 of this report.

Table 10-1 Adopted blockage factors for the 5% and 1% AEP event sensitivity analysis

Drainage Structure	Design Blockage	Increased Blockage	Decreased Blockage
Figtree Gully bridges and culverts (opening width < 1.5 m)	50%	100%	25%
Figtree Gully bridges and culverts (opening width ≥ 1.5 m)	10%	20%	0%
Kingdon Ponds and Middle Brook bridges over Liverpool St	0%	10%	0%
Parsons Gully culverts through Liverpool St	15%	25%	0%

Drainage Structure	Design Blockage	Increased Blockage	Decreased Blockage
Stormwater Drainage Network (diameter < 0.6 m)	50%	100%	25%
Stormwater Drainage Network (diameter ≥ 0.6 m)	25%	50%	0%

Impacts of the changes in adopted blockage factors on 5% AEP peak flood levels are summarised as follows:

- Increase in blockage factors:
  - Peak flood levels along Parsons Gully, Kingdon Ponds and Middle Brook are relatively insensitive to increased blockage at the Liverpool Street bridges / culverts, with peak flood levels expected to change by less than 0.05 metres.
  - Peak flood levels along Figtree Gully are also relatively insensitive to increased blockage in the stormwater network and drainage system within Scone. A localised area along Figtree Gully upstream of Liverpool Street exhibits a flood level increase of up to 0.1 metres.
  - Increased blockage of culverts beneath the railway is expected to impact flooding along the minor overland flow paths which cross the railway. Flood levels are predicted to increase by between 0.2 and 0.3 metres in localised areas upstream of the railway. This also results in localised flood level increases of up to 0.2 metres along some flow paths downstream of the railway as flows are direct to the north and south along the railway line.
- Decrease in blockage factors:
  - Peak flood levels along Parsons Gully, Kingdon Ponds and Middle Brook are relatively insensitive to decreased blockage at the Liverpool Street bridges / culverts, with peak flood levels expected to change by less than 0.05 metres.
  - Peak flood levels along Figtree Gully are also relatively insensitive to decreased blockage in the stormwater network and drainage system within Scone. A localised area along Figtree Gully upstream of Liverpool Street exhibits a flood level decrease of up to 0.11 metres.
  - Decreased blockage of culverts beneath the railway are expected to impact flooding along the minor overland flow paths which cross the railway. Flood levels are generally predicted to decrease by up to 0.2 metres in localised areas upstream of the railway. Flood levels downstream of the railway expected to increase by less than 0.05 metres.

Impacts of the changes in hydraulic roughness on 1% AEP peak flood levels are summarised as follows:

- Increase in blockage factors:
  - Peak flood levels along Parsons Gully, Kingdon Ponds and Middle Brook are relatively insensitive to increased blockage at the Liverpool Street bridges / culverts, with peak flood levels expected to change by less than 0.05 metres.
  - Peak flood levels along Figtree Gully are also relatively insensitive to increased blockage in the stormwater network and drainage system within Scone. A localised area along Figtree Gully upstream of Liverpool Street exhibits a flood level increase of up to 0.07 metres.

- Increased blockage of culverts beneath the railway are expected to impact flooding along the minor overland flow paths which cross the railway. Flood levels are predicted to increase by up to 0.2 metres in localised areas upstream of the railway. This also results in localised flood level increases of up to 0.2 metres along some flow paths downstream of the railway as flows are direct to the north and south along the railway line.

- Decrease in blockage factors:
  - Peak flood levels along Parsons Gully, Kingdon Ponds and Middle Brook are relatively insensitive to decreased blockage at the Liverpool Street bridges / culverts, with peak flood levels expected to change by less than 0.05 metres.
  - Peak flood levels along Figtree Gully are also relatively insensitive to decreased blockage in the stormwater network and drainage system within Scone. A localised area along Figtree Gully upstream of Liverpool Street exhibits a flood level decrease of up to 0.07 metres.
  - Decreased blockage of culverts beneath the railway are expected to impact flooding along the minor overland flow paths which cross the railway. Flood levels are generally predicted to decrease by up to 0.15 metres in localised areas upstream of the railway. Flood levels downstream of the railway expected to increase by less than 0.05 metres.

10.3. Sensitivity to Hydraulic Roughness

The sensitivity of 5% and 1% AEP event peak flood levels to hydraulic roughness has been tested by applying a 25% increase and a 25% decrease in the adopted values for the baseline design flood conditions. The impacts of a 25% increase and decrease in hydraulic roughness on modelled peak flood levels for the 5% and 1% AEP event are presented in Volume 2 of this report.

Impacts of the changes in hydraulic roughness on 5% AEP peak flood levels are summarised as follows:

- 25% increase in hydraulic roughness:
  - Peak flood levels along Parsons Gully in the vicinity of Scone typically increased by 0.1 to 0.2 metres.
  - Peak flood levels along Kingdon Ponds, Middle Brook and the Satur overland flow path exhibited only small increases generally less than 0.05 metres.
  - Peak flood levels along Figtree Gully typically increased by between 0.05 and 0.1 metres in areas upstream of Main Street. Increases in peak flood level were typically less than 0.05 metres in the vicinity of Kelly Street and the Scone CBD.
  - Increases in peak flood level along other minor tributaries and local overland flow paths were generally less than 0.05 metres.
- 25% decrease in hydraulic roughness:
  - Peak flood levels along Parsons Gully in the vicinity of Scone typically decreased by 0.1 to 0.2 metres, with a localised decrease of about 0.32 metres predicted near Liverpool Street and the Scone Bypass.
  - Peak flood levels along Kingdon Ponds and Middle Brook exhibited decreases of up to 0.1 metres.

- Peak flood levels along the Satur overland flow path generally decreased by less than 0.05 metres.
- Peak flood levels along Figtree Gully typically decreased by up to 0.1 metres in areas upstream of Main Street, with some areas exhibiting localised decreases of up to 0.2 metres. Decreases in peak flood level were typically less than 0.05 metres in the vicinity of Kelly Street and the Scone CBD.
- Decreases in peak flood level along other minor tributaries and local overland flow paths were generally less than 0.05 metres.

Impacts of the changes in hydraulic roughness on 1% AEP peak flood levels are summarised as follows:

- 25% increase in hydraulic roughness:
  - Peak flood levels along Parsons Gully in the vicinity of Scone typically increased by 0.1 to 0.2 metres, with some areas exhibiting localised increases of between 0.2 and 0.3 metres (e.g. at Liverpool Street near the Scone Bypass).
  - Peak flood levels along Kingdon Ponds and Middle Brook exhibited increases of up to 0.1 metres.
  - Peak flood levels along the Satur overland flow path generally increased by less than 0.05 metres.
  - Peak flood levels along Figtree Gully typically increased by up to 0.1 metres in areas upstream of Main Street, with some areas exhibiting localised increases of up to 0.2 metres. Increases in peak flood level were typically less than 0.05 metres in the vicinity of Kelly Street and the Scone CBD.
  - Increases in peak flood level along other minor tributaries and local overland flow paths were generally less than 0.05 metres.
- 25% decrease in hydraulic roughness:
  - Peak flood levels along Parsons Gully in the vicinity of Scone typically decreased by 0.1 to 0.2 metres, with a localised decrease of about 0.33 metres predicted near Liverpool Street and the Scone Bypass.
  - Peak flood levels along Kingdon Ponds and Middle Brook exhibited decreases of up to 0.2 metres.
  - Peak flood levels along the Satur overland flow path generally decreased by less than 0.05 metres.
  - Peak flood levels along Figtree Gully typically decreased by up to 0.1 metres in areas upstream of Main Street, with some areas exhibiting localised decreases of up to 0.2 metres. Decreases in peak flood level were typically less than 0.05 metres in the vicinity of Kelly Street and the Scone CBD.
  - Decreases in peak flood level along other minor tributaries and local overland flow paths were generally less than 0.05 metres.

10.4. Sensitivity to Rainfall Losses

The sensitivity of the WBNM hydrologic model to variations in rainfall loss rates was tested for the 5% and 1% AEP events by comparing flow hydrographs along Middle Brook, Kingdon Ponds, Parsons

Gully and Figtree Gully for lower and higher loss rates, respectively. The loss rates tested in this sensitivity analysis are summarised in the following:

- Increased loss rates: IL = 50 mm, CL = 2.5 mm/hr.
- Decreased loss rates: IL = 10 mm, CL = 1 mm/hr.

These variations in loss rates were selected with reference to the range of losses adopted by previous studies in the vicinity of Scone (refer **Table 6-2**).

Flow hydrographs were extracted from the WBNM model and compared against the flow hydrographs for the adopted design loss rates of IL = 30 mm and CL = 1.5 mm/hr. The flow hydrograph comparison is shown in **Figure B-9** to **Figure B-16** in **Appendix B**.

11. References

Advisian (*2022*), '*Scone CBD Revitalisation Project – Flood Impact Assessment*', prepared for Upper Hunter Shire Council

Austroads (*1994*), '*Waterway Design – A Guide to the Hydraulic Design of Bridges*'.

Babister M, Trim A, Testoni I, Retallick M (*2016*), '*The Australian Rainfall & Runoff Datahub*', 37th Hydrology and Water Resources Symposium Queenstown NZ.

Ball J, Babister M, Nathan R, Weeks W, Weinmann E, Retallick M, Testoni I, (Editors) (*2019*), '*Australian Rainfall and Runoff: A Guide to Flood Estimation*', © Commonwealth of Australia (Geoscience Australia), (ARR 2019).

Bewsher Consulting Pty Ltd (*1999*), '*Scone Floodplain Management Study and Plan*', prepared for Scone Shire Council.

Chow VT (*1959*), '*Open-Channel Hydraulics*'

Cohn et. Al (*2013*), '*A generalized Grubbs-Beck test statistic for detecting multiple potentially influential low outliers in flood series*', Water Resour. Res., 49(8), 5047-5058.

CSIRO and Bureau of Meteorology (*2015*), *'Climate Change in Australia – Information for Australia's Natural Resource Management Regions: Technical Report'*

Department of Land and Water Conservation (DLWC) (*1996*), '*Scone Flood Study*'.

Department of Natural Resources and Water (*2007*), '*Queensland Urban Drainage Manual*', Volume 1, Second Edition 2007.

Department of Planning and Environment (*2023*), '*Flood risk management manual – the policy and manual for the management of flood liable land*'.

Department of Planning and Environment (*2023*), '*Flood risk management guideline FB02 – Flood Function*'.

IPCC (Intergovernmental Panel on Climate Change) (*2013*), *'Climate Change 2013: The Physical Science Basis, Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change'*, Stocker, T.F., and others (Eds.), Cambridge University Press, Cambridge, UK and New York, NY, USA

NSW Department of Environment and Climate Change (*2007*), *'Floodplain Risk Management Guideline – Practical Consideration of Climate Change'*.

RHM Consulting Engineers (*2021*), '*Kelly Street Revitalisation Project Concept Design*', Revision CD9.

Appendix A
Additional Information on Model Calibration and Validation

Table of Contents

List of Figures

List of Tables

A1. Development of Rating Curves

Recorded water level data was available from the following stream gauges for use in the model calibration:

- Bureau of Meteorology gauges (no rating curves provided)
  - 561101 Cressfield
  - 561099 Dry Creek
  - 561100 Wingen
  - 61360 Scone (Kingdon Ponds)
- Water NSW gauge (rating curve provided)
  - 210093 Kingdon Ponds near Parkville

To enable direct comparison with flow hydrographs simulated by the WBNM hydrologic model the recorded water level hydrographs must be converted to flows. A rating curve was available for the 210093 Kingdon Ponds near Parkville gauge to convert the recorded water levels into flows. However, no rating curves were available to convert the recorded water level data into flows for the remaining gauges.

Accordingly, Worley Consulting developed a series of rating curves to approximate the flows at these gauge locations from the recorded depths using the following approach.

(i) A cross-section of the relevant channel and floodplain at each gauge was extracted from the best available LiDAR DEM (1m DEM in lower catchment, 5m DEM in upper catchment) along with the apparent channel slope.

(ii) A Manning's 'n' hydraulic roughness coefficient value of 0.06 was estimated based on review of available photography and with reference to the *Scone Flood Study* (DLWC 1996) and values recommended in the literature (e.g., ARR 2019).

(iii) A 'best estimate' rating curve was produced from this information using the Manning's Equation to compute flow rates at regular depth intervals.

(iv) A 'lower bound' rating curve was produced at each location by increasing the roughness coefficient to 0.08 and decreasing the slope by 20%.

(v) An 'upper bound' rating curve was produced by decreasing the roughness coefficient to 0.04 and increasing the slope by 20%.

The resulting rating curves are shown in **Figure A 1** to **Figure A 4**.

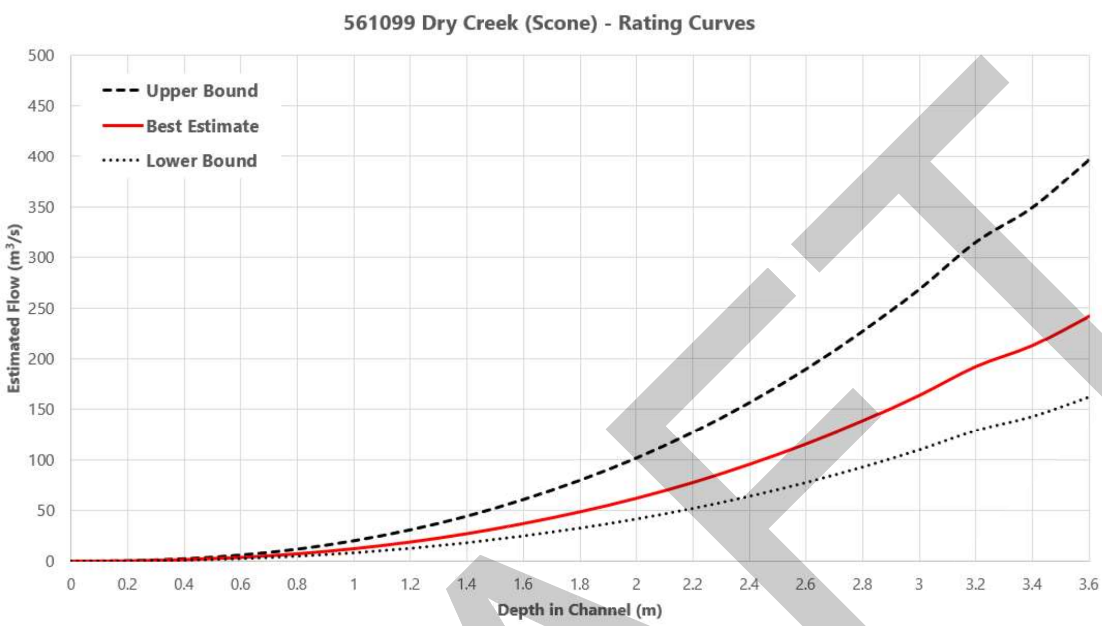


Figure A 1 Approximated Rating Curves at the 561099 Dry Creek (Scone) Gauge

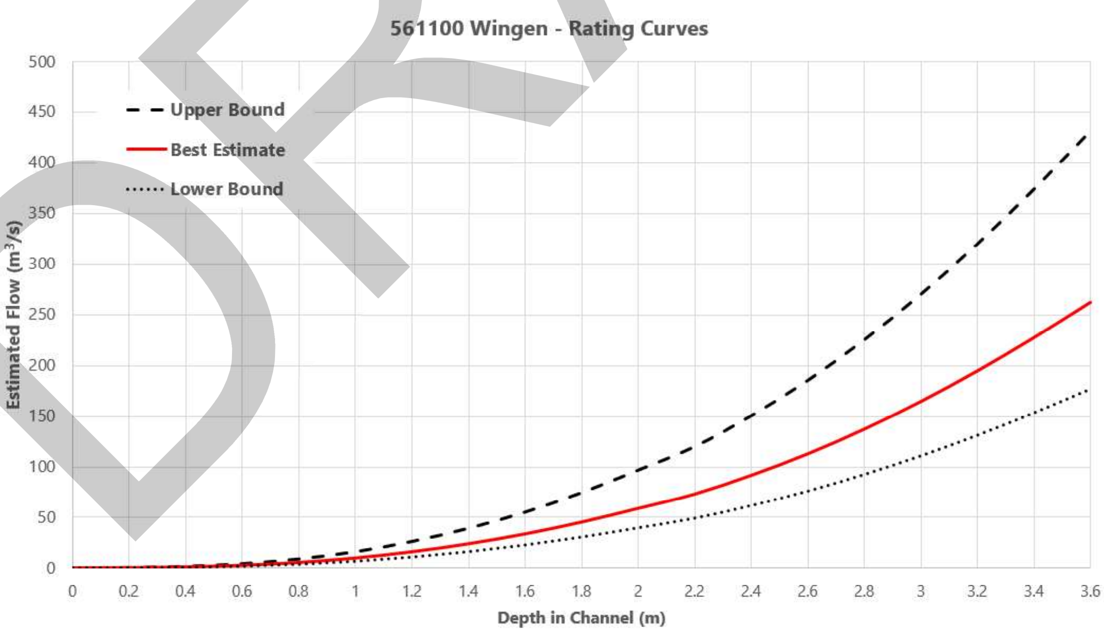


Figure A 2 Approximated Rating Curves at the 561100 Wingen Gauge

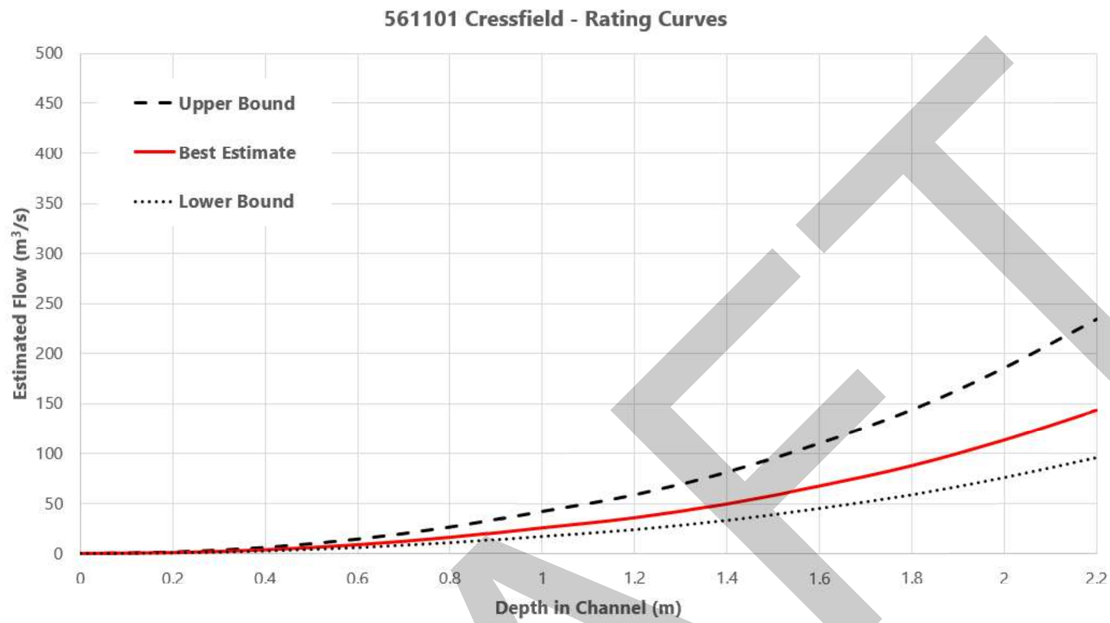


Figure A 3 Approximated Rating Curves at the 561101 Cressfield Gauge

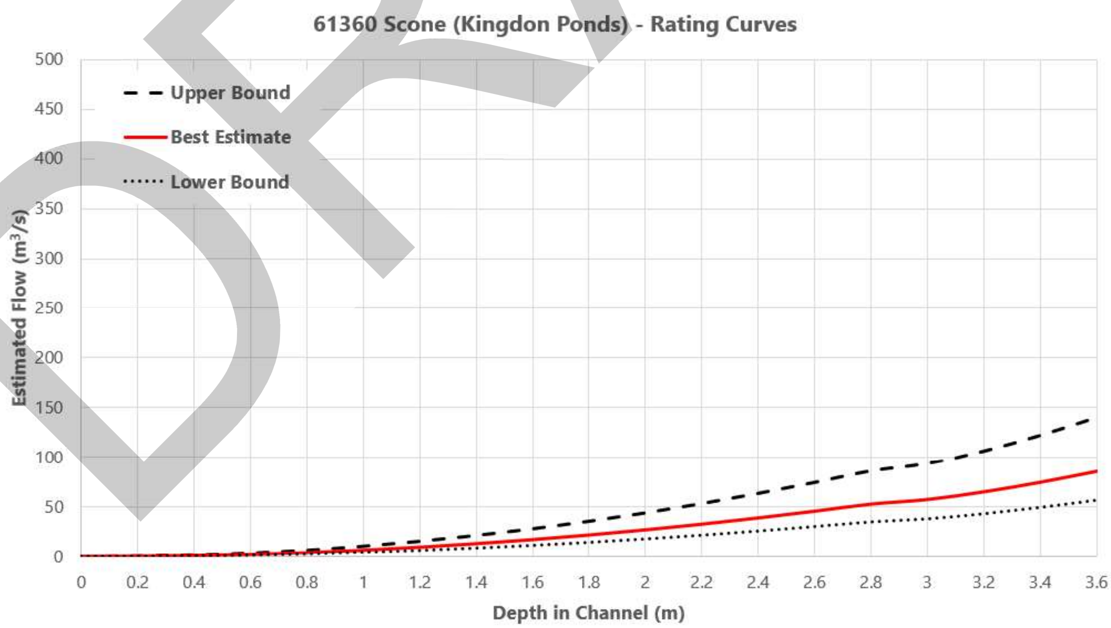


Figure A 4 Approximated Rating Curves at the 61360 Scone (Kingdon Ponds) Gauge

A2. Comparison of Drone Footage to TUFLOW Model Results for the November 2021 Event

The extent of flooding predicted by the TUFLOW model were compared against available drone footage from the November 2021 flood event at several locations in the vicinity of Scone. The drone footage was captured by a Council staff member at about 1:30 pm on 26 November, which is close to the peak of the event.

Location 1 - Aberdeen Street

The drone footage shows that the intersection of Liverpool Street and Aberdeen Street is not inundated during the November 2021 event. The footage also shows that the lot on the south-western corner of this intersection of is also flood-free. This compares well to the flood extents predicted by the TUFLOW model (refer **Figure A 5**).

Floodwaters are shown to have inundated large sections of Aberdeen Street to the south of the Liverpool Street intersection, particularly on the western side of the street. This flood behaviour has also been replicated in the TUFLOW hydraulic model.

Location 2 - Liverpool Street

The flood model results predict that most of Liverpool Street between Scone and Satur was not overtopped at the peak of the November 2021 event, except for an approximate 100 metre stretch of road between Parsons Gully and Kingdon Ponds.

This minor overtopping of Liverpool Street was also captured on the drone footage (refer **Figure A 6**).

Location 3 - Parsons Gully and Kingdon Ponds Floodplain (north of Liverpool St)

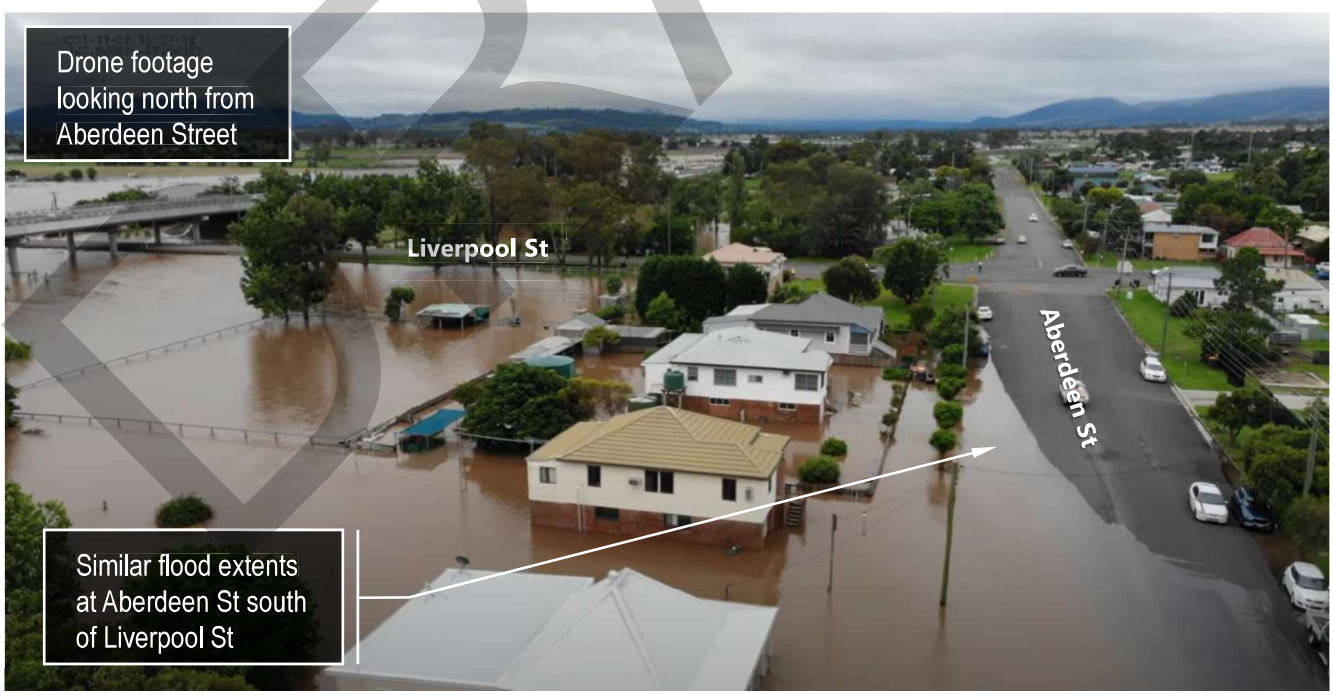
The drone footage shows that floodwaters have spilled out of the banks of both Parsons Gully and Kingdon Ponds in the vicinity of the properties just north of Liverpool Street, creating a continuous body of water between the two watercourses. This has resulted in the inundation of several of the properties on the floodplain between Parsons Gully and Kingdon Ponds.

The drone footage also shows that there is a distinct separation of floodwaters between Kingdon Ponds and Parsons Gully to the north of this area. The recorded flood behaviour has been replicated in the TUFLOW model results (refer **Figure A 7**).

Location 4 - Parsons Gully and Kingdon Ponds Floodplain (south of Liverpool St)

The TUFLOW hydraulic model was also able to reasonably replicate the extents of flooding in the areas to the south of Liverpool Street between Kingdon Ponds and Parsons Gully. The drone footage shows the shallow inundation of Wingen Street as well as the flooding around the perimeter of the playing field to the south of Wingen Street. These flood extents are also seen in the TUFLOW model results (refer **Figure A 8**).

FIGURE A 5



UPPER HUNTER SHIRE COUNCIL

Prepared by:

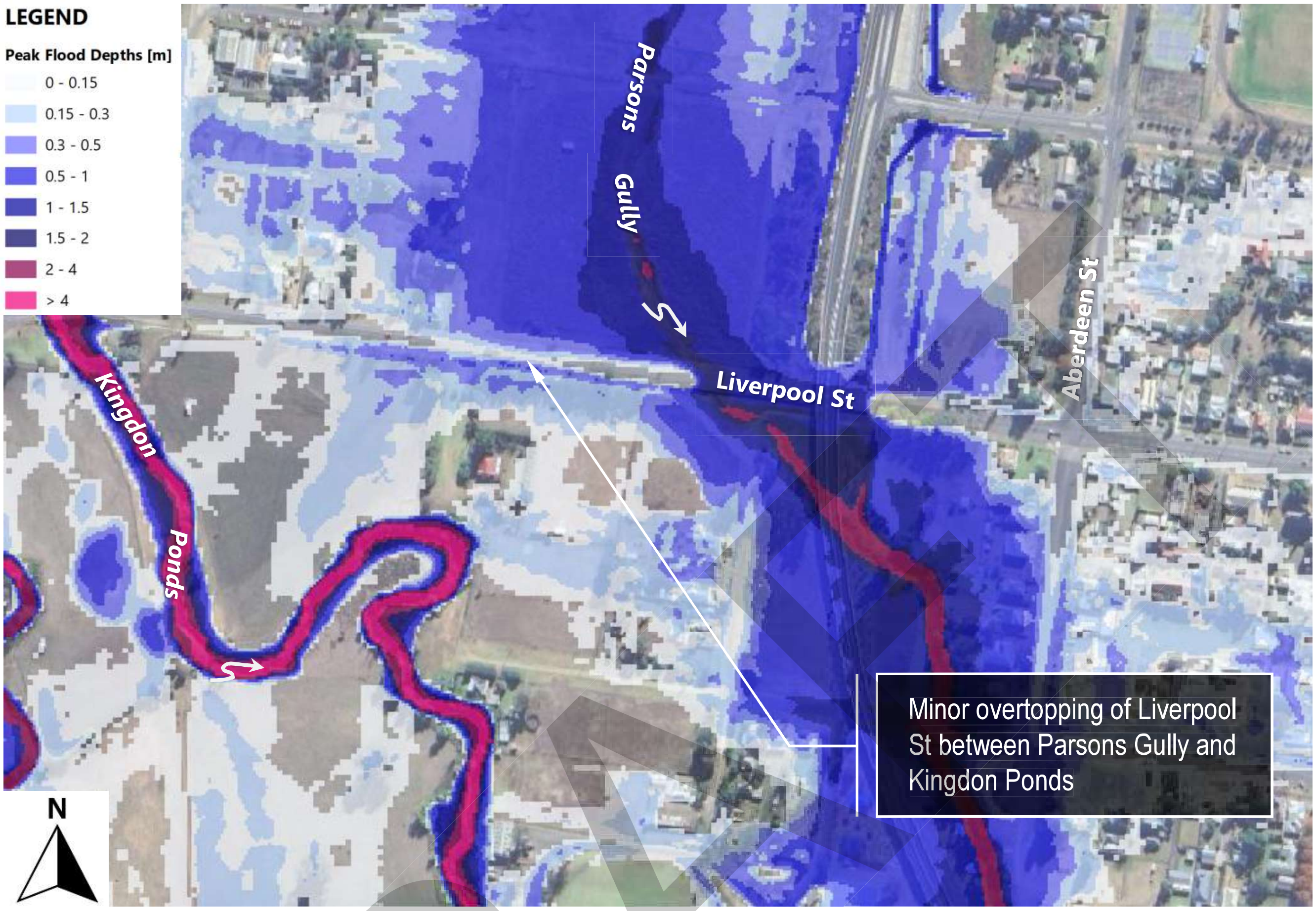
worley consulting

211019_Scone_TUFLOW.qgs

fg311015-00018_220304_ReportFigs_A4P.pdf

COMPARISON OF TUFLOW MODEL RESULTS AND RECORDED DRONE FOOTAGE DURING THE NOV 2021 EVENT – LOCATION 1

FIGURE A 6



Prepared by:

worley consulting

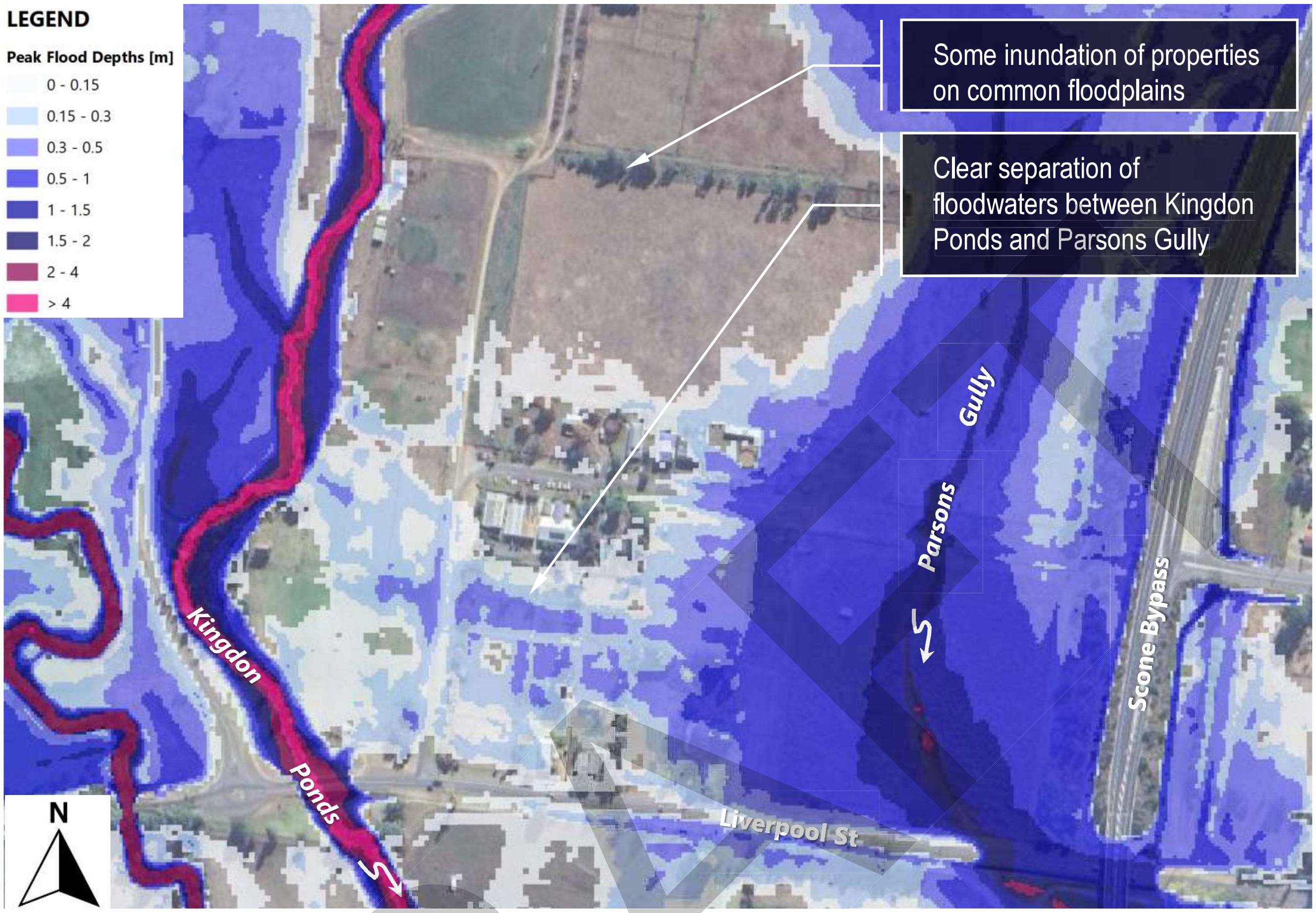
211019_Scone_TUFLOW.qgs

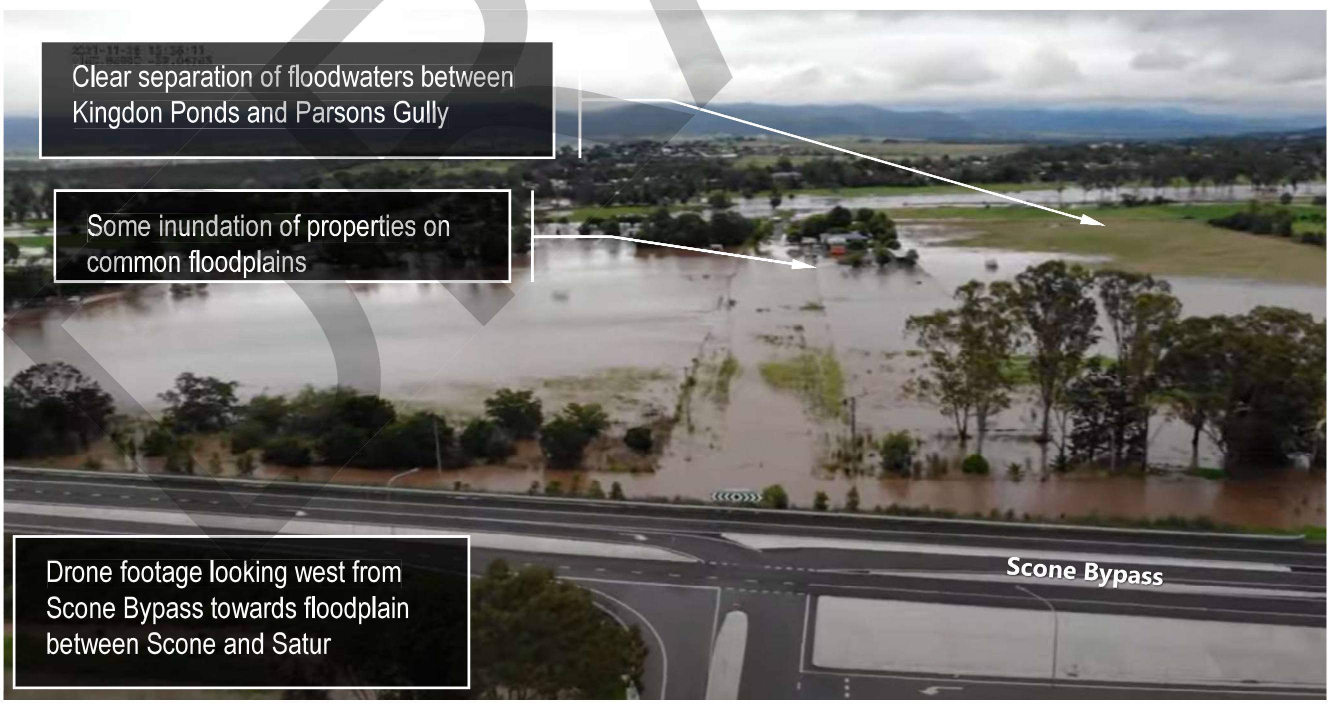
fg311015-00018_220304_ReportFigs_A4P.pdf

UPPER HUNTER SHIRE COUNCIL

COMPARISON OF TUFLOW MODEL RESULTS AND RECORDED DRONE FOOTAGE DURING THE NOV 2021 EVENT – LOCATION 2

FIGURE A 7





Prepared by:

worley consulting

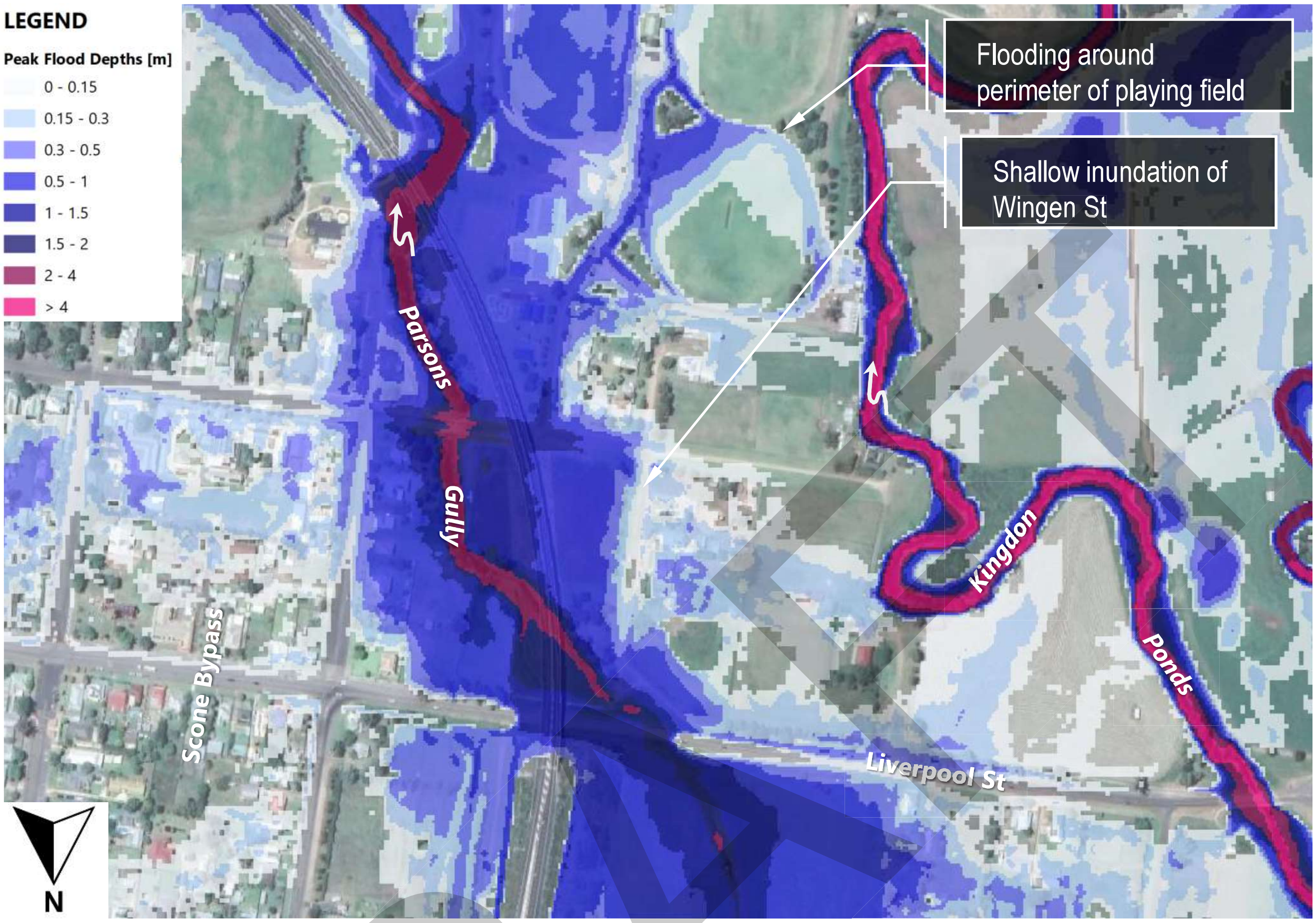
211019_Scone_TUFLOW.qgs

fg311015-00018_220304_ReportFigs_A4P.pdf

UPPER HUNTER SHIRE COUNCIL

COMPARISON OF TUFLOW MODEL RESULTS AND RECORDED DRONE FOOTAGE DURING THE NOV 2021 EVENT – LOCATION 3

FIGURE A 8



Prepared by:

worley consulting

211019_Scone_TUFLOW.qgs

fg311015-00018_220304_ReportFigs_A4P.pdf

UPPER HUNTER SHIRE COUNCIL

COMPARISON OF TUFLOW MODEL RESULTS AND RECORDED DRONE FOOTAGE DURING THE NOV 2021 EVENT – LOCATION 4

A3. Findings from the Scone CBD Revitalisation Project

A3.1. Background

In parallel with its work for the Scone FRMS Project, Worley Consulting (*then Advisian*) was engaged by Upper Hunter Shire Council to provide flood and stormwater drainage advice to support the Scone CBD Revitalisation Project. Worley Consulting's role was to investigate flooding within the Scone CBD caused by rainfall in the Figtree Gully catchment and to assess options for reducing the frequency of inundation of properties along Kelly Street.

The relevant sub-catchments from the WBNM model developed for the Scone Flood Study were adopted for the hydrologic assessment of the Figtree Gully catchment. A total of 26 sub-catchments were analysed and values of 0.9 and 1.0 were initially adopted for the runoff lag factor 'C' and stream routing lag factor 'F', respectively. These parameters were determined through the calibration and verification process described in **Section 5** of the Flood Study.

A3.2. Need for Verification of the WBNM 'C' Factor

Following discussions with Council, it was agreed that the runoff lag factor 'C' should be verified for the Figtree Gully catchment for the following reasons:

(i) Although a 'C' factor of 0.9 was determined as part of the Scone Flood Study through a detailed calibration / verification process (refer **Section 5** of this report), the calibration / verification was completed based on consideration of streamflow gauges located <u>outside</u> of the Figtree Gully catchment. No streamflow records exist within the Figtree Gully catchment.

(ii) A 'C' factor of 0.9 is considered relatively low. Low 'C' factors lead to higher peak flows and 'flashier' flow hydrographs and are likely to result in higher peak flood levels and velocities. As an example, flow hydrographs for the Scone CBD were extracted from the truncated WBNM model for 'C' factors of 0.9, 1.3 and 1.6, for the 10% AEP design event (refer **Figure A 9)**. **Figure A 9** shows that adoption of different values of 'C' would result in material differences to the peak flow and shape of the hydrograph.

Peak flows at the Figtree Gully outlet determined by Worley Consulting's hydrologic analysis (for C = 0.9, 1.3 and 1.6) were compared against those documented in the 1999 *Scone Floodplain Management Study and Plan* (Bewsher Consulting), as well as flows estimated by the Regional Flood Frequency Estimation Model (RFFEM) tool (https://rffe.arr-software.org/). The comparison (refer **Table A 1** below) shows that peak flows for a 'C' factor of 0.9 are significantly higher than corresponding flows documented in the 1999 FRMS and derived from the RFFEM tool, and therefore, suggests that a 'C' factor of 1.3 or 1.6 may be more appropriate for the Figtree Gully catchment.

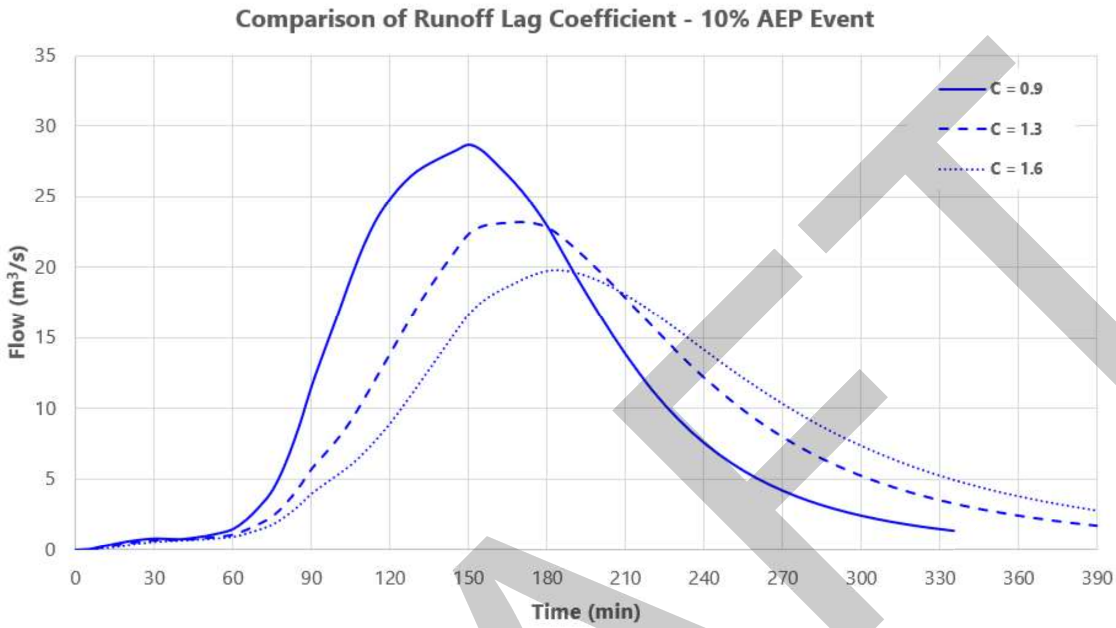


Figure A 9 Comparison of Flow Hydrographs at the Scone CBD for Varying Runoff Coefficients

Table A 1 Comparison of Peak Flows at the Figtree Gully Outlet (m^3/s)

Storm Event	ADV WBNM C = 0.9	ADV WBNM C = 1.3	ADV WBNM C = 1.6	1999 FRMS	RFFEM Best Estimate
50% AEP	12.5	9.6	8.3	N/A	5.2
20% AEP	24.5	17.5	14.9	14.1	12
10% AEP	30.6	23.9	20.1	17.3	18.6
5% AEP	36.6	28.9	24.4	22.1	26.9

A3.3. Verification to the February 1992 Historic Flood Event

In recognition of this, Worley Consulting opted to investigate the February 1992 historic flood event to verify an appropriate value of 'C' for the Figtree Gully catchment. This event was chosen as pluviograph data is available from the nearby gauge at Scone Airport (gauge number 61363). Additionally, although there are no streamflow gauges in the Figtree Gully catchment, the 1999 FRMS contains a number of detailed descriptions of the flood behaviour for this event. The cumulative rainfall for the February 1992 historic event is shown in **Figure A 10**. The analysis was focused on the rainfall which occurred between 9:00 pm on 7 February 1992 and 6:00pm on 9 February 1992.

Rainfall totals were also extracted from two daily read rainfall gauges located in the vicinity of the Figtree Gully catchment (refer **Figure A 11**). The rainfall temporal pattern from the 61363 pluviograph was applied to these rainfall totals.

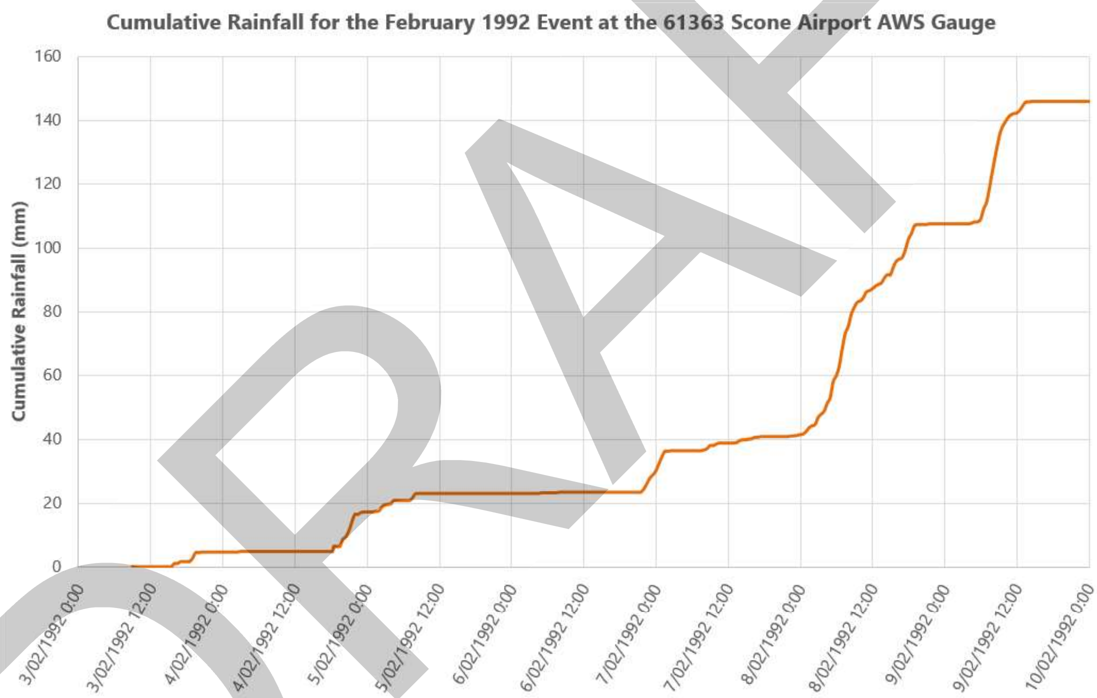
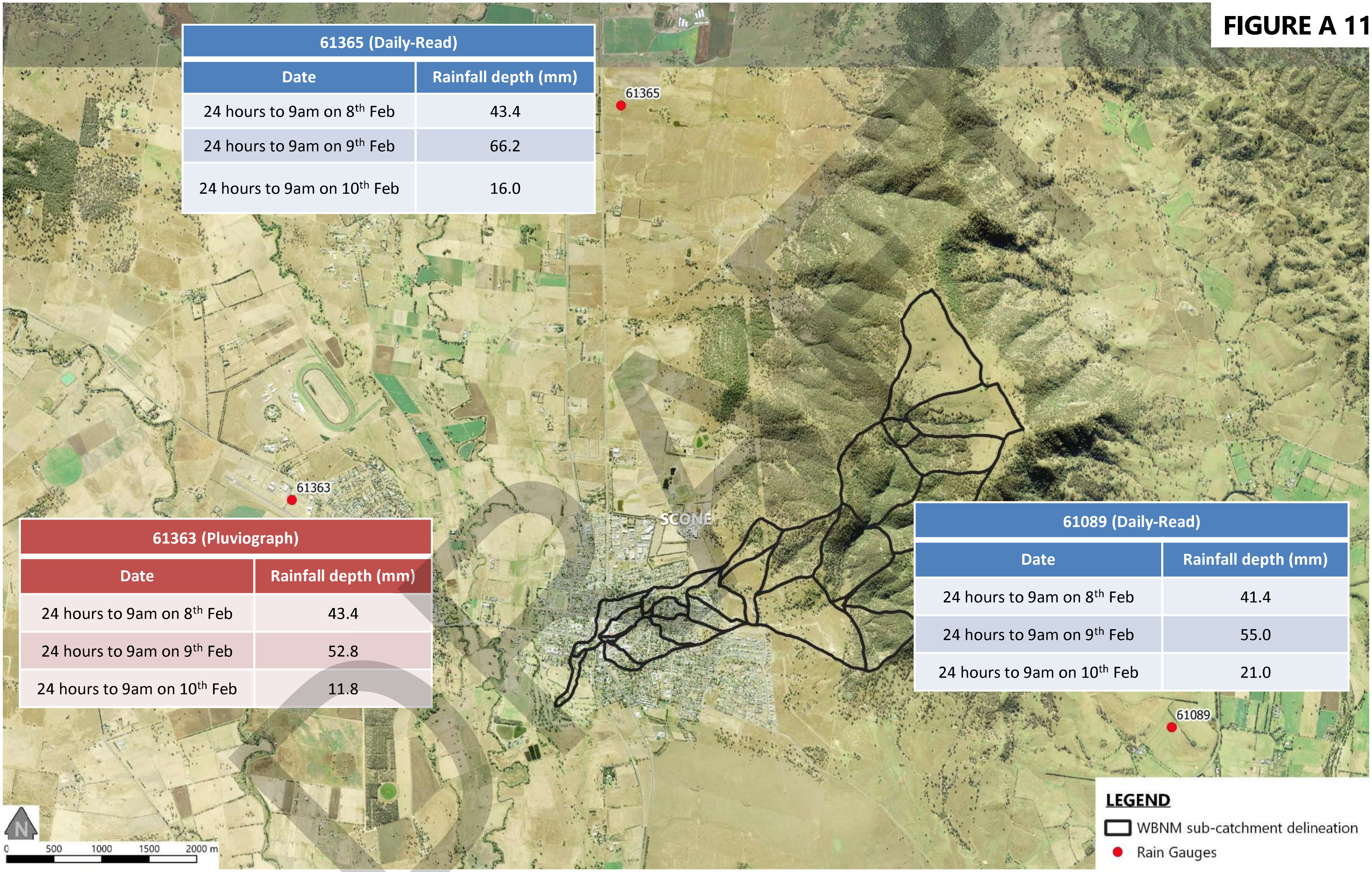


Figure A 10 Cumulative Rainfall for the February 1992 Event

FIGURE A 11



61365 (Daily-Read)	
Date	Rainfall depth (mm)
24 hours to 9am on 8th Feb	43.4
24 hours to 9am on 9th Feb	66.2
24 hours to 9am on 10th Feb	16.0

61363 (Pluviograph)	
Date	Rainfall depth (mm)
24 hours to 9am on 8th Feb	43.4
24 hours to 9am on 9th Feb	52.8
24 hours to 9am on 10th Feb	11.8

61089 (Daily-Read)	
Date	Rainfall depth (mm)
24 hours to 9am on 8th Feb	41.4
24 hours to 9am on 9th Feb	55.0
24 hours to 9am on 10th Feb	21.0

Prepared by: Worley consulting

UPPER HUNTER SHIRE COUNCIL

ADOPTED RAINFALL RECORDS FOR VERIFICATION OF THE FIGTREE GULLY HYDROLOGIC MODEL TO THE FEBRUARY 1992 HISTORIC EVENT

A3.4. Flood Modelling of the February 1992 Event

Worley Consulting tested four different values for the runoff lag factor 'C' (0.9, 1.1, 1.3 and 1.6) to determine which value for 'C' would result in the closest fit to the flood descriptions in the 1999 Scone FRMS. The following loss rates were adopted:

- Initial loss of 0 mm, due to approximately 40 mm of rainfall occurring in the five days preceding the storm.
- A continuing loss rate of 0.6 mm/hr, as per ARR Data Hub guidelines.

Following numerous trials, the described flood behaviour could not be replicated without assuming significant blockage in the Figtree Gully channel between Park and Barton Streets, which is considered unrealistic. Flooding due to overland flow was reported at several properties on Waverley Street, Oxford Street and Park Street, which was not observed in the flood model results.

Conversely, properties on St Aubins Street adjacent to the Figtree Gully channel were reported by residents to be unaffected by flooding during the 1992 event, whereas these areas were predicted to be flooded by Worley Consulting's flood model. These discrepancies were observed in the model results for all four tested values of the runoff lag factor 'C'.

It was concluded that it is likely that a local storm burst occurred over the Scone CBD and the lower reaches of the Figtree Gully catchment extending immediately to the east and that this storm was not captured in the available rainfall data for the 1992 event.

The 'C' factor was thus adopted based only on flood behaviour in the Scone CBD. The flood descriptions found in the 1999 Scone FRMS reported relatively minor above-floor flooding for some businesses fronting Kelly Street. The flood model results for a 'C' factor of 1.3 led to the closest match to described flood behaviour in the Scone CBD.

Accordingly, it is recommended that a 'C' factor of 1.3 be adopted for the Figtree Gully catchment.

A3.5. Update to the Scone Flood Study WBNM Hydrologic Model

The WBNM hydrologic model developed for the FRMS&P project will be updated to adopt a 'C' factor of 1.3 for the Figtree Gully catchment, in accordance with the findings from the Scone CBD Revitalisation Project. The value of the 'C' factor for the catchments of Middle Brook, Kingdon Ponds and Parsons Gully will remain at 0.9, as per the calibration process described in **Section 5** of the Flood Study report.

The final calibrated hydrologic parameters are summarised in **Table A 2** below.

It is emphasised that the adoption of a 'C' factor of 1.3 in the Figtree Gully catchment will not impact on the calibration and validation results presented in **Section 5** of the Flood Study report. The calibration and validation presented in these sections were completed based on stream gauges located along Middle Brook and Kingdon Ponds.

Following the update to the Figtree Gully catchment, the WBNM hydrologic model can be adopted to complete design hydrologic modelling.

Table A 2 Updated WBNM Model Parameters

Area	Runoff Lag Factor 'C'	Stream Routing Lag Factor 'F'
Upper Middle Brook Catchment	0.9	0.5
Upper Dry Creek Catchment	0.9	0.8
Upper Kingdon Ponds Catchment	0.9	1.0
Figtree Gully Catchment	1.3	1.0
Other Mid to Lower Catchments	0.9	Generally 1.0 (Higher values for sub-catchments with high stream length to area ratio)

Appendix B
Hydrologic Model Analysis & Results

Table of Contents

List of Figures

List of Tables

B1. Critical Duration and Temporal Pattern Analysis

The WBNM hydrologic model was used to determine critical storm durations, associated temporal patterns and average peak design flows at eight (8) key locations:

- Overland flow path at Scone north of Figtree Gully;
- Overland flow path at Scone south of Figtree Gully;
- Overland flow path at Satur;
- Figtree Gully at Kelly Street;
- Figtree Gully at outlet to Parsons Gully;
- Parsons Gully at Liverpool Street;
- Middle Brook at Liverpool Street;
- Kingdon Ponds at Liverpool Street.

From this a number of critical storm durations and associated temporal patterns of interest were identified for further investigation for each flood magnitude.

From the investigated storms, three durations were selected for each flood magnitude that in combination provided the overall best match to 'average peak design flows' across the assessment locations.

A comparison of peak design flood flows from the selected storm duration and temporal pattern combinations above with the average peak flow from the temporal pattern ensemble at each site are presented for the eight design events in **Table B 1** to **Table B 8**.

It is noted that the resulting peak flood flows are generally comparable to the averaged peak flood flows, within a range of percentage difference that is typical of the ARR 2019 temporal pattern ensemble approach (i.e., 5% to 10%). However, selected peak flood flows for Parsons Gully and Middle Brook for some design events differ by more than 10% when compared to the averaged peak flow. The adoption of these flows for Parsons Gully and Middle Brook is considered immaterial given that the flows from Kingdon Ponds are much larger. As such, flooding along Kingdon Ponds is expected to result in peak flood conditions in the floodplain between Satur and Scone.

Table B 1 Critical duration and temporal pattern assessment for the 20% AEP event

Sub-catchment Information		All Durations and Patterns						Selected Durations and Patterns				
Location	U/S Area (km^2)	Critical Duration (min)	Av. Peak Flow (m^3/s)	Av. Pattern Set	Av. Patt. Peak Flow (m^3/s)	% Diff to Av.	ARF	Selected Duration (min)	Selected Pattern Set	Selected Patt. Peak Flow (m^3/s)	% Diff to Av.	ARF
Scone Overland Flows (south of Gully)	0.73	360	2.78	4740	3.42	23.0%	1.00	360	4738	2.76	-0.7%	1.00
Scone Overland Flows (north of Gully)	1.03	360	3.69	4740	4.59	24.4%	1.00	360	4738	3.55	-3.8%	1.00
Satur Overland Flows	2.14	360	5.48	4738	5.61	2.4%	1.00	360	4738	5.61	2.4%	1.00
Figtree Gully at Kelly St	6.41	540	11.06	4770	11.16	0.9%	1.00	540	4776	11.46	3.6%	1.00
Figtree Gully Outlet	6.85	540	11.6	4770	11.7	0.9%	1.00	540	4776	12.07	4.1%	1.00
Parsons Gully at Liverpool St	32.14	540	56.17	4776	56.34	0.3%	0.95	540	4776	56.34	0.3%	1.00
Middle Brook at Liverpool St	73.47	1080	80.23	4846	84.61	5.5%	0.97	540	4776	80.21	0.0%	1.00
Kingdon Ponds at Liverpool St	211.09	1080	186.45	104	191.57	2.7%	0.95	1080	104	191.57	2.7%	0.95

Table B 2 Critical duration and temporal pattern assessment for the 10% AEP event

Sub-catchment Information		All Durations and Patterns						Selected Durations and Patterns				
Location	U/S Area (km^2)	Critical Duration (min)	Av. Peak Flow (m^3/s)	Av. Pattern Set	Av. Patt. Peak Flow (m^3/s)	% Diff to Av.	ARF	Selected Duration (min)	Selected Pattern Set	Selected Patt. Peak Flow (m^3/s)	% Diff to Av.	ARF
Scone Overland Flows (south of Gully)	0.73	120	3.39	4624	3.46	2.1%	1.00	180	4663	3.31	-2.4%	1.00
Scone Overland Flows (north of Gully)	1.03	120	4.39	4630	4.5	2.5%	1.00	180	4663	4.39	0.0%	1.00
Satur Overland Flows	2.14	270	6.54	4699	6.83	4.4%	1.00	180	4663	6.55	0.2%	1.00
Figtree Gully at Kelly St	6.41	540	15.04	4764	16.62	10.5%	1.00	360	4726	14.94	-0.7%	1.00
Figtree Gully Outlet	6.85	540	15.81	4764	17.51	10.8%	1.00	360	4726	15.9	0.6%	1.00
Parsons Gully at Liverpool St	32.14	540	75.89	4764	84.68	11.6%	0.95	360	4726	80.64	6.3%	1.00
Middle Brook at Liverpool St	73.47	540	103.94	4763	106.96	2.9%	0.94	360	4726	101.54	-2.3%	1.00
Kingdon Ponds at Liverpool St	211.09	720	249.48	11	287.34	15.2%	0.91	1080	104	255.06	2.2%	0.95

Table B 3 Critical duration and temporal pattern assessment for the 5% AEP event

Sub-catchment Information		All Durations and Patterns						Selected Durations and Patterns				
Location	U/S Area (km^2)	Critical Duration (min)	Av. Peak Flow (m^3/s)	Av. Pattern Set	Av. Patt. Peak Flow (m^3/s)	% Diff to Av.	ARF	Selected Duration (min)	Selected Pattern Set	Selected Patt. Peak Flow (m^3/s)	% Diff to Av.	ARF
Scone Overland Flows (south of Gully)	0.73	120	4.83	4630	4.84	0.2%	1.00	120	4628	4.69	-2.9%	1.00
Scone Overland Flows (north of Gully)	1.03	120	6.3	4628	6.34	0.6%	1.00	120	4628	6.34	0.6%	1.00
Satur Overland Flows	2.14	180	8.72	4663	8.99	3.1%	1.00	120	4628	8.78	0.7%	1.00
Figtree Gully at Kelly St	6.41	540	18.25	4764	19.76	8.3%	1.00	360	4696	18.7	2.5%	1.00
Figtree Gully Outlet	6.85	540	19.23	4764	20.84	8.4%	1.00	360	4696	19.66	2.2%	1.00
Parsons Gully at Liverpool St	32.14	540	91.53	4764	99.92	9.2%	0.95	360	4696	106.82	16.7%	1.00
Middle Brook at Liverpool St	73.47	540	132.05	4763	136.25	3.2%	0.93	360	4696	135.38	2.5%	1.00
Kingdon Ponds at Liverpool St	211.09	720	314.15	11	368.01	17.1%	0.91	1080	104	316.75	0.8%	0.95

Table B 4 Critical duration and temporal pattern assessment for the 2% AEP event

Sub-catchment Information		All Durations and Patterns						Selected Durations and Patterns				
Location	U/S Area (km^2)	Critical Duration (min)	Av. Peak Flow (m^3/s)	Av. Pattern Set	Av. Patt. Peak Flow (m^3/s)	% Diff to Av.	ARF	Selected Duration (min)	Selected Pattern Set	Selected Patt. Peak Flow (m^3/s)	% Diff to Av.	ARF
Scone Overland Flows (south of Gully)	0.73	90	6.35	4585	6.39	0.6%	1.00	90	4585	6.39	0.6%	1.00
Scone Overland Flows (north of Gully)	1.03	90	8.4	4532	8.46	0.7%	1.00	90	4585	8.64	2.9%	1.00
Satur Overland Flows	2.14	120	12.44	4618	14	12.5%	1.00	90	4585	12.22	-1.8%	1.00
Figtree Gully at Kelly St	6.41	720	24.78	4785	25.72	3.8%	1.00	360	4694	25.3	2.1%	1.00
Figtree Gully Outlet	6.85	720	26.07	4785	27.16	4.2%	1.00	360	4694	26.59	2.0%	1.00
Parsons Gully at Liverpool St	32.14	720	125.99	4443	128.53	2.0%	0.95	360	4694	147.49	17.1%	1.00
Middle Brook at Liverpool St	73.47	720	174.58	4747	191.49	9.7%	0.94	360	4694	173.66	-0.5%	1.00
Kingdon Ponds at Liverpool St	211.09	720	404.59	15	478.02	18.1%	0.90	1080	104	401.23	-0.8%	0.95

Table B 5 Critical duration and temporal pattern assessment for the 1% AEP event

Sub-catchment Information		All Durations and Patterns						Selected Durations and Patterns				
Location	**U/S Area (km^2)**	**Critical Duration (min)**	**Av. Peak Flow (m^3/s)**	**Av. Pattern Set**	**Av. Patt. Peak Flow (m^3/s)**	**% Diff to Av.**	**ARF**	**Selected Duration (min)**	**Selected Pattern Set**	**Selected Patt. Peak Flow (m^3/s)**	**% Diff to Av.**	**ARF**
Scone Overland Flows (south of Gully)	0.73	90	7.69	4585	7.76	0.9%	1.00	90	4585	7.76	0.9%	1.00
Scone Overland Flows (north of Gully)	1.03	120	10.19	4618	10.65	4.5%	1.00	90	4585	10.46	2.6%	1.00
Satur Overland Flows	2.14	120	15.37	4618	17.45	13.5%	1.00	90	4585	15.89	3.4%	1.00
Figtree Gully at Kelly St	6.41	720	28.45	4785	29.3	3.0%	1.00	360	4596	27.58	-3.1%	1.00
Figtree Gully Outlet	6.85	720	29.99	4785	30.95	3.2%	1.00	360	4596	29.38	-2.0%	1.00
Parsons Gully at Liverpool St	32.14	720	144.26	4785	146.47	1.5%	0.95	360	4596	142.93	-0.9%	1.00
Middle Brook at Liverpool St	73.47	720	203.62	4747	219.6	7.8%	0.93	360	4596	224.95	10.5%	1.00
Kingdon Ponds at Liverpool St	211.09	720	473.13	15	554.88	17.3%	0.90	1080	104	466.04	-1.5%	0.95

Table B 6 Critical duration and temporal pattern assessment for the 1 in 200 AEP event

Sub-catchment Information		All Durations and Patterns						Selected Durations and Patterns				
Location	U/S Area (km^2)	Critical Duration (min)	Av. Peak Flow (m^3/s)	Av. Pattern Set	Av. Patt. Peak Flow (m^3/s)	% Diff to Av.	ARF	Selected Duration (min)	Selected Pattern Set	Selected Patt. Peak Flow (m^3/s)	% Diff to Av.	ARF
Scone Overland Flows (south of Gully)	0.73	60	9.57	4558	9.59	0.2%	1.00	60	4558	9.59	0.2%	1.00
Scone Overland Flows (north of Gully)	1.03	60	12.69	4405	12.71	0.2%	1.00	60	4558	12.77	0.6%	1.00
Satur Overland Flows	2.14	90	18.62	4532	19.1	2.6%	1.00	60	4558	18.59	-0.2%	1.00
Figtree Gully at Kelly St	6.41	180	33.74	4651	33.86	0.4%	1.00	180	4651	33.86	0.4%	1.00
Figtree Gully Outlet	6.85	180	35.16	4648	35.42	0.7%	1.00	180	4651	35.59	1.2%	1.00
Parsons Gully at Liverpool St	32.14	720	162.75	4785	163.79	0.6%	0.94	180	4651	201.5	23.8%	1.00
Middle Brook at Liverpool St	73.47	720	232.96	4747	246.29	5.7%	0.92	180	4651	207.26	-11.0%	1.00
Kingdon Ponds at Liverpool St	211.09	720	539.04	15	628.24	16.5%	0.95	1080	104	527.43	-2.2%	0.95

Table B 7 Critical duration and temporal pattern assessment for the 1 in 500 AEP event

Sub-catchment Information		All Durations and Patterns						Selected Durations and Patterns				
Location	U/S Area (km²)	Critical Duration (min)	Av. Peak Flow (m³/s)	Av. Pattern Set	Av. Patt. Peak Flow (m³/s)	% Diff to Av.	ARF	Selected Duration (min)	Selected Pattern Set	Selected Patt. Peak Flow (m³/s)	% Diff to Av.	ARF
Scone Overland Flows (south of Gully)	0.73	60	12.38	4559	13.13	6.1%	1.00	60	4558	12.1	-2.3%	1.00
Scone Overland Flows (north of Gully)	1.03	60	16.48	4559	17.61	6.9%	1.00	60	4558	16.14	-2.1%	1.00
Satur Overland Flows	2.14	90	23.65	4532	24.19	2.3%	1.00	60	4558	23.85	0.8%	1.00
Figtree Gully at Kelly St	6.41	120	42.72	4614	43.89	2.7%	1.00	120	4614	43.89	2.7%	1.00
Figtree Gully Outlet	6.85	120	43.97	4614	45.29	3.0%	1.00	120	4614	45.29	3.0%	1.00
Parsons Gully at Liverpool St	32.14	720	189.87	4443	193	1.6%	0.94	120	4614	266.05	40.1%	1.00
Middle Brook at Liverpool St	73.47	720	275.28	4747	284.26	3.3%	0.92	120	4614	227.84	-17.2%	1.00
Kingdon Ponds at Liverpool St	211.09	720	632.87	15	732.14	15.7%	0.88	1080	104	614.46	-2.9%	0.95

Table B 8 Critical duration and temporal pattern assessment for the PMF event

Sub-catchment Information		All Durations		Selected Durations		
Location	U/S Area (km^2)	Critical Duration (min)	PMF Peak Flow (m^3/s)	Selected Duration (min)	Selected Duration Peak Flow (m^3/s)	% Diff. to Av.
Scone Overland Flows (south of Gully)	0.73	30	59.91	30	59.91	0.0%
Scone Overland Flows (north of Gully)	1.03	30	80.28	30	80.28	0.0%
Satur Overland Flows	2.14	60	135.77	90	134.65	-0.8%
Figtree Gully at Kelly St	6.41	90	330.57	90	330.57	0.0%
Figtree Gully Outlet	6.85	90	347.96	90	347.96	0.0%
Parsons Gully at Liverpool St	32.14	90	1827.99	90	1827.99	0.0%
Middle Brook at Liverpool St	73.47	180	2508.55	180	2508.55	0.0%
Kingdon Ponds at Liverpool St	211.09	180	6620.15	180	6620.15	0.0%

B2. Design Flood Hydrographs

Design flood hydrographs simulated using the WBNM hydrologic model are presented for the following key locations:

- Figtree Gully at Kelly Street in the Scone Central Business District (refer **Figure B 1**and **Figure B 2**);
- Parsons Gully at Liverpool Street (refer **Figure B 3** and **Figure B 4**);
- Middle Brook at Liverpool Street (refer **Figure B 5** and **Figure B 6**); and
- Kingdon Ponds at Liverpool Street (refer **Figure B 7** and **Figure B 8**).

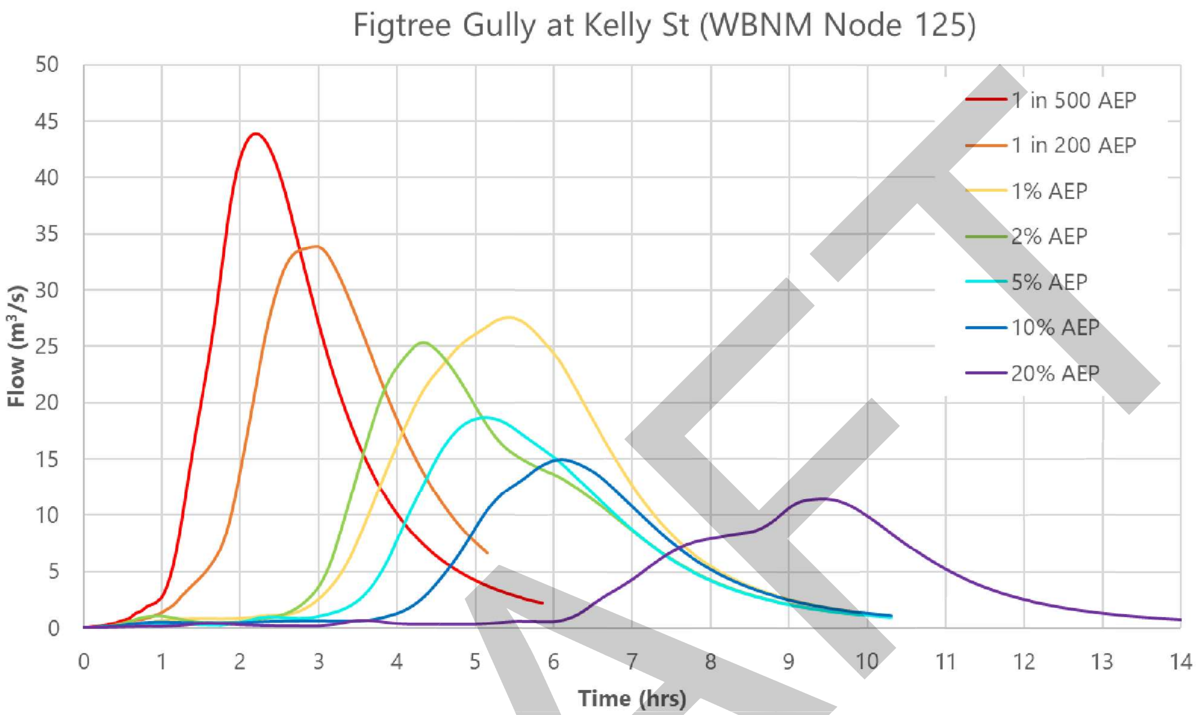


Figure B 1 **Design flow hydrographs along Figtree Gully at Kelly Street**

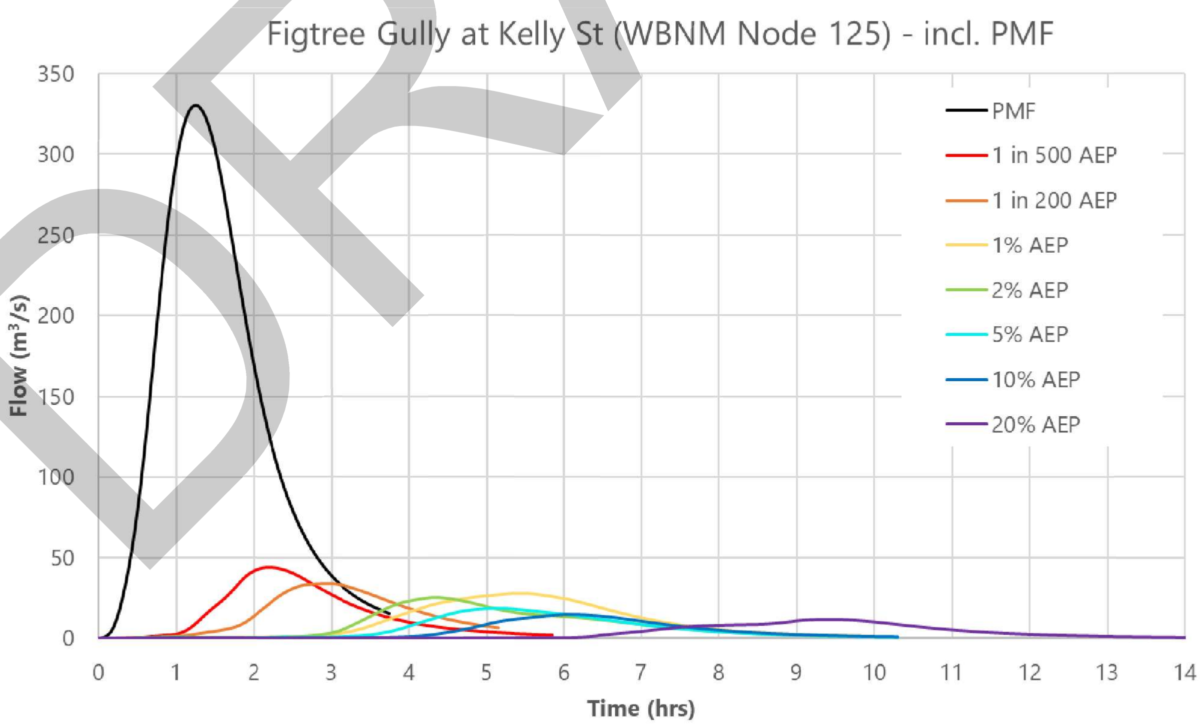


Figure B 2 **Design flow hydrographs along Figtree Gully at Kelly Street (incl. PMF)**

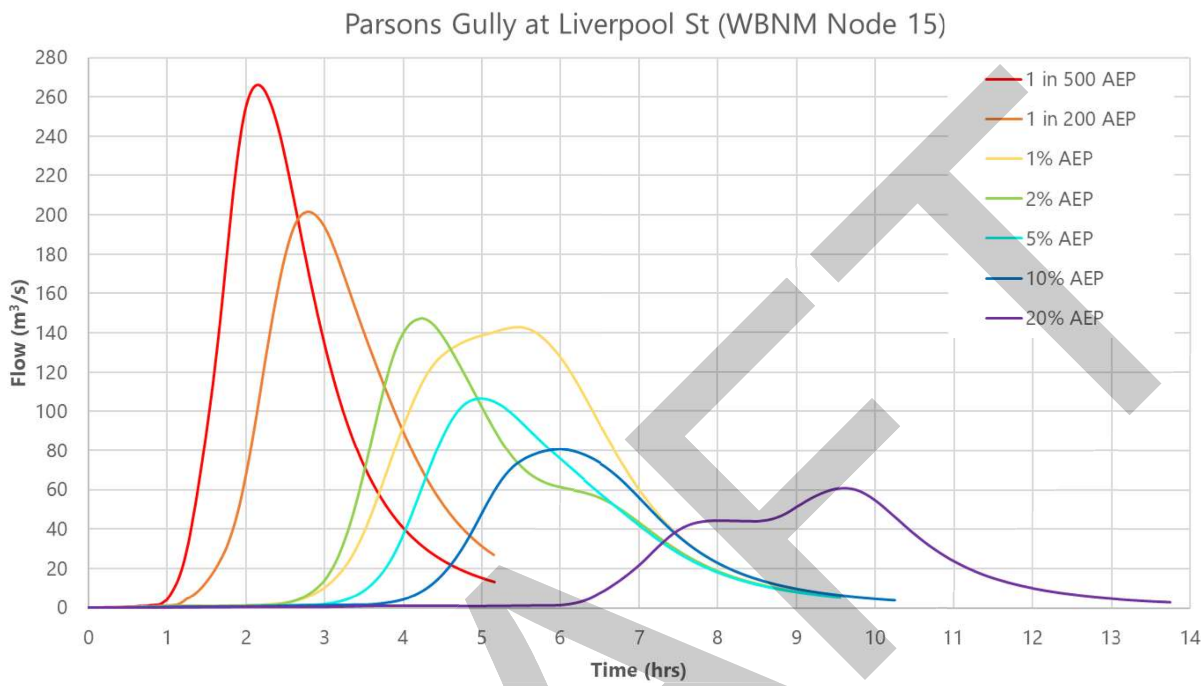


Figure B 3 Design flow hydrographs along Parsons Gully at Liverpool Street

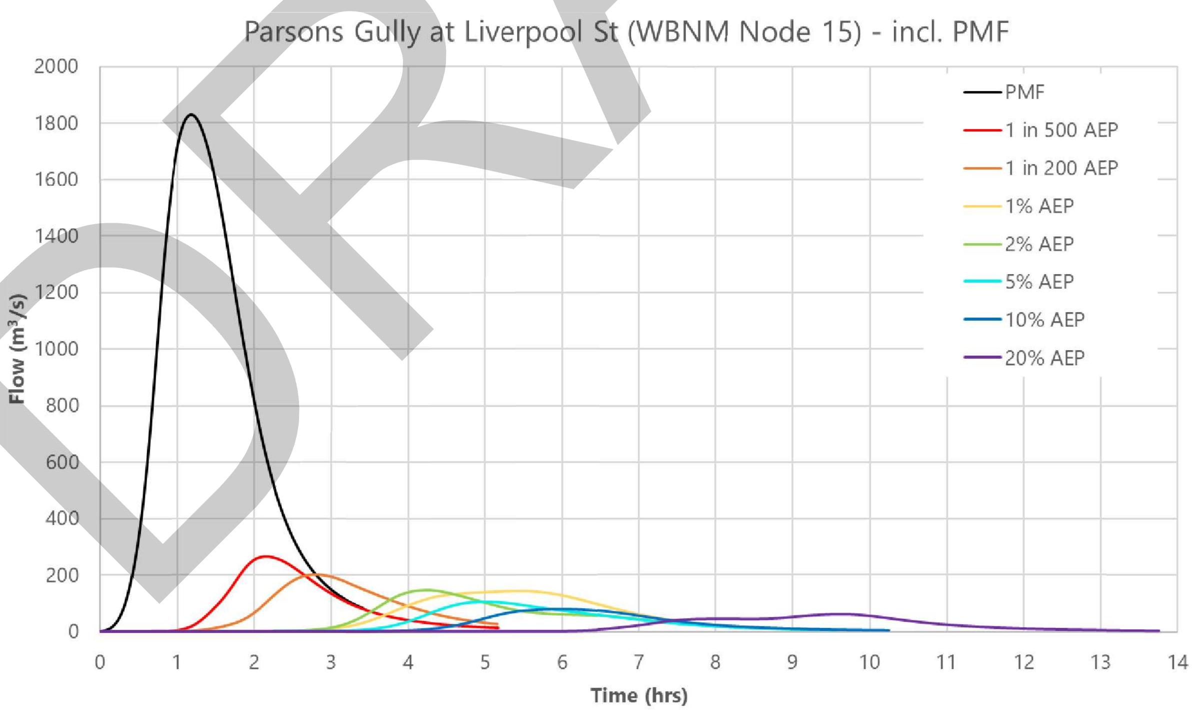


Figure B 4 Design flow hydrographs along Parsons Gully at Liverpool Street (incl. PMF)

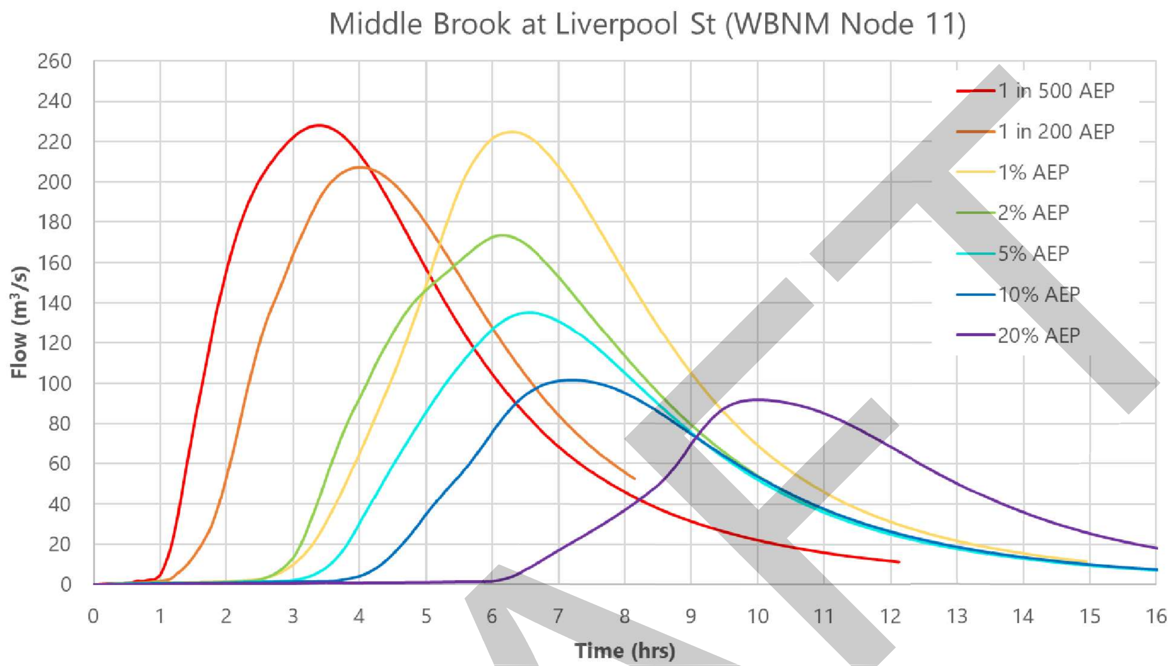


Figure B 5 Design flow hydrographs along Middle Brook at Liverpool Street

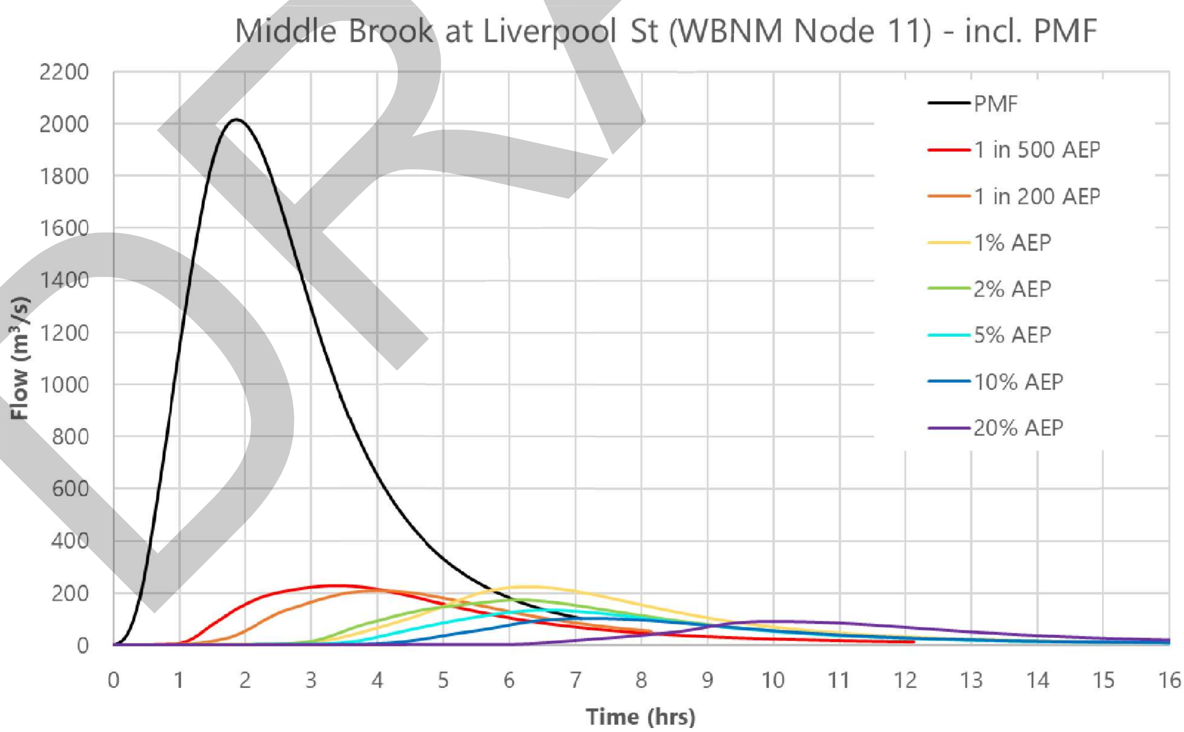


Figure B 6 Design flow hydrographs along Middle Brook at Liverpool Street (incl. PMF)

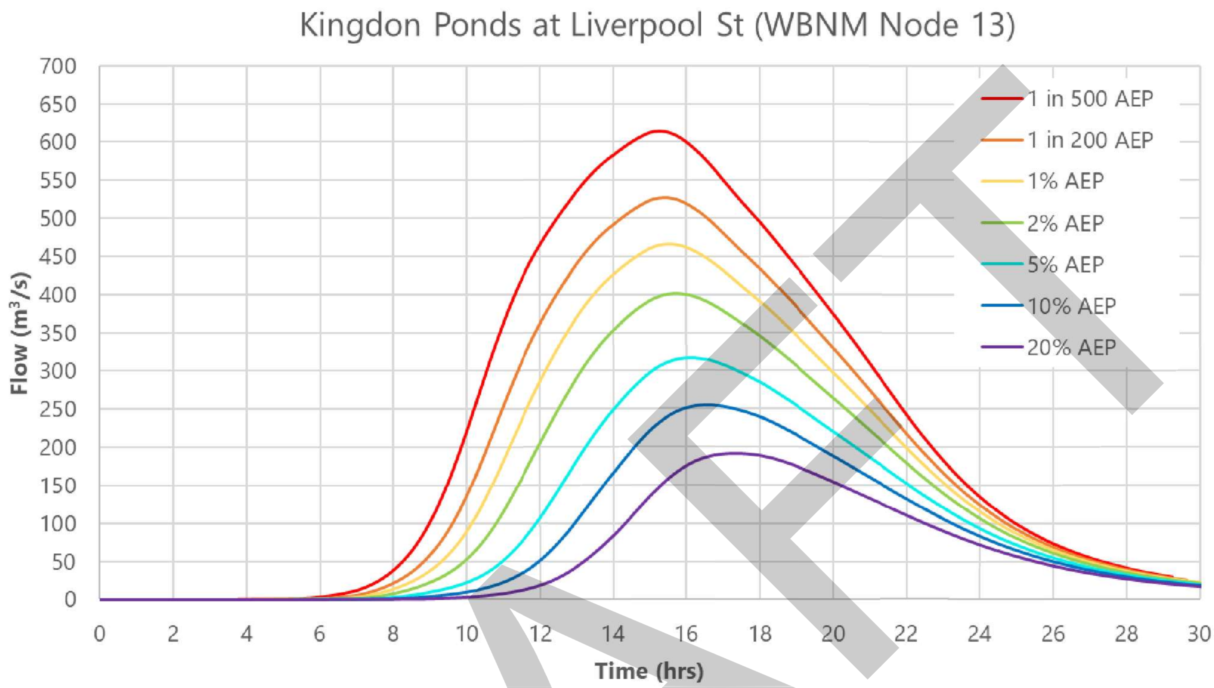


Figure B 7 Design flow hydrographs along Kingdon Ponds at Liverpool Street

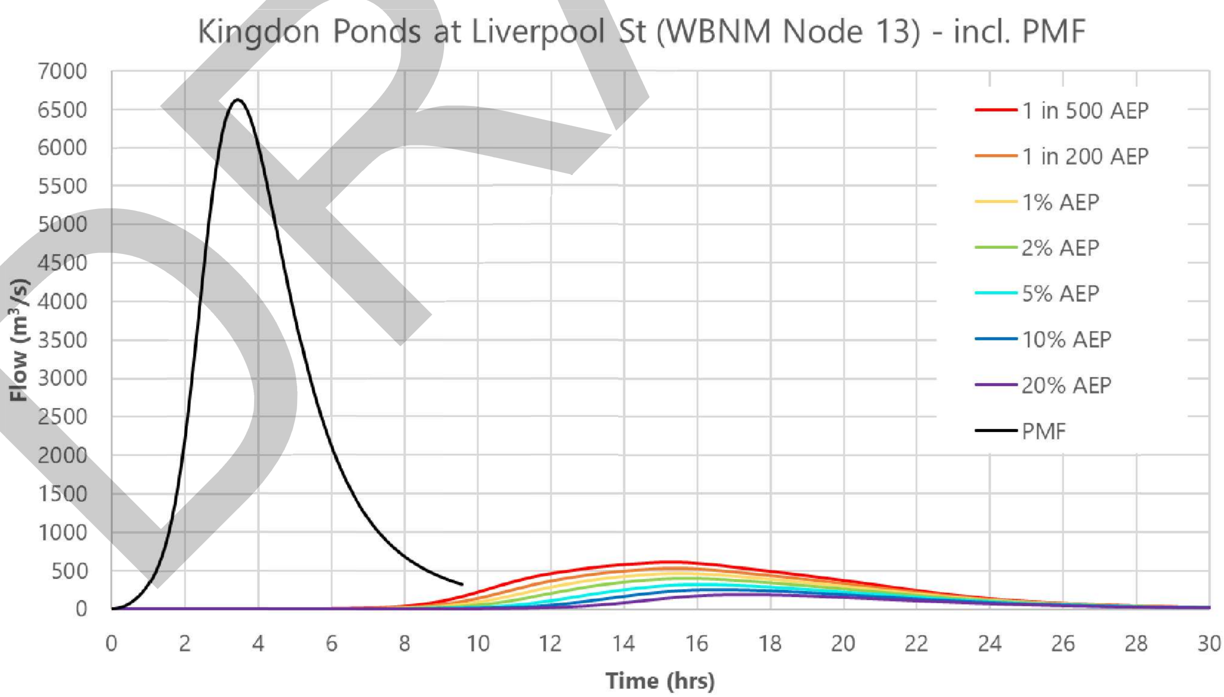


Figure B 8 Design flow hydrographs along Kingdon Ponds at Liverpool Street (incl. PMF)

B3. WBNM Rainfall Loss Sensitivity Analysis

The sensitivity of the WBNM hydrologic model to variations in rainfall loss rates was tested for the 5% and 1% AEP events by comparing flow hydrographs along Middle Brook, Kingdon Ponds, Parsons Gully and Figtree Gully for lower and higher loss rates, respectively. The loss rates tested in this sensitivity analysis are summarised in the following:

- Increased loss rates: IL = 50 mm, CL = 2.5 mm/hr.
- Decreased loss rates: IL = 10 mm, CL = 1 mm/hr.

These variations in loss rates were selected with reference to the range of losses adopted by previous studies in the vicinity of Scone (refer **Table B 9**).

Table B 9 Comparison of rainfall loss rates in other studies

Study	Calibration Losses	Losses Adopted for Design Modelling
Scone Flood Study (*DLWC, 1996*)	IL = 10 to 80 mm CL = 2.5 mm/h	IL = 30 to 60 mm CL = 2.5 mm/h
Aberdeen Flood Study (*WMAwater, 2013*)	IL = 5 to 50 mm CL = 1 to 2.5 mm/h	IL = 30 mm CL = 2.5 mm/h
Upper Hunter River Flood Study (*WorleyParsons, 2014*)	IL = 5 to 80 mm CL = 0.5 to 2.5 mm/h	IL = 20 to 40 mm CL = 1 to 2.5 mm/h
Updated Upper Hunter River Flood Study (*Royal Haskoning DHV, 2017*)	IL = 15 to 30 mm CL = 1.5 mm/h	IL = 20 to 50 mm CL = 1.5 mm/h
Current Study (*Worley Consulting, 2024*)	IL = 10 to 50 mm CL = 1.9 to 2.5 mm/h	IL = 30 mm CL = 1.5 mm/h (PMF: IL = 0 mm, CL = 1 mm/h)

Flow hydrographs were extracted from the WBNM model and compared against the flow hydrographs for the adopted design loss rates of IL = 30 mm and CL = 1.5 mm/hr. The flow hydrograph comparison is shown in **Figure B 9** to **Figure B 16**.

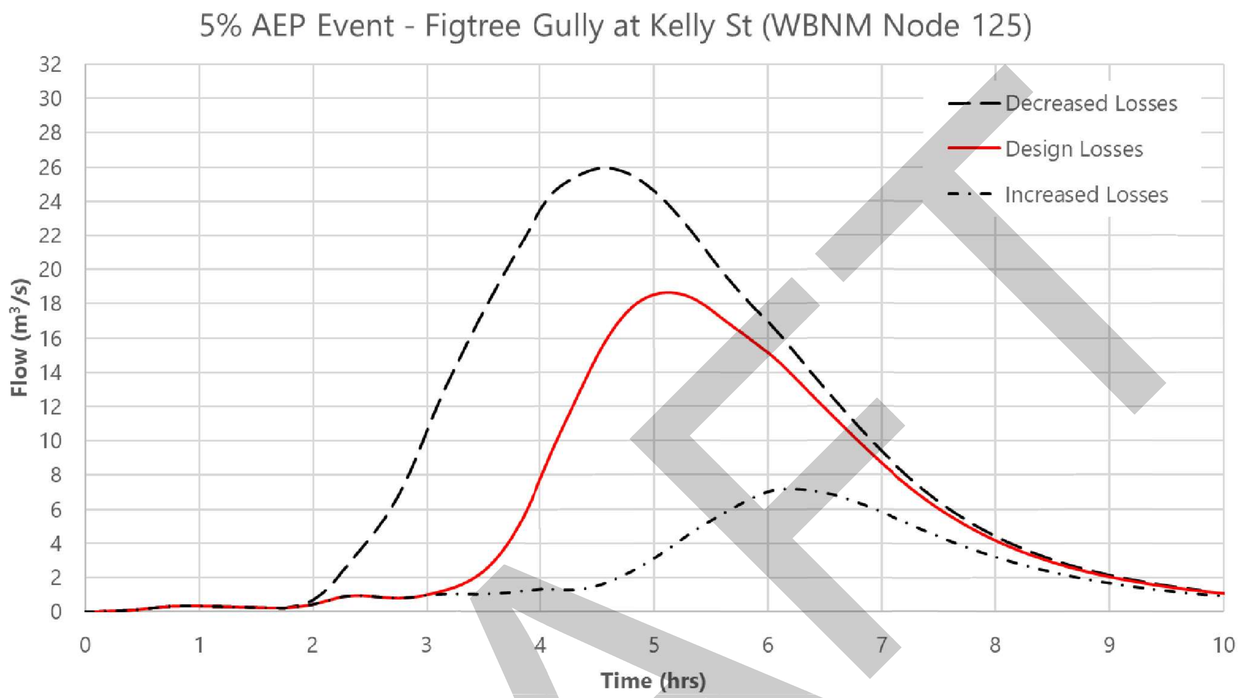


Figure B 9 5% AEP rainfall loss sensitivity analysis along Figtree Gully at Kelly Street

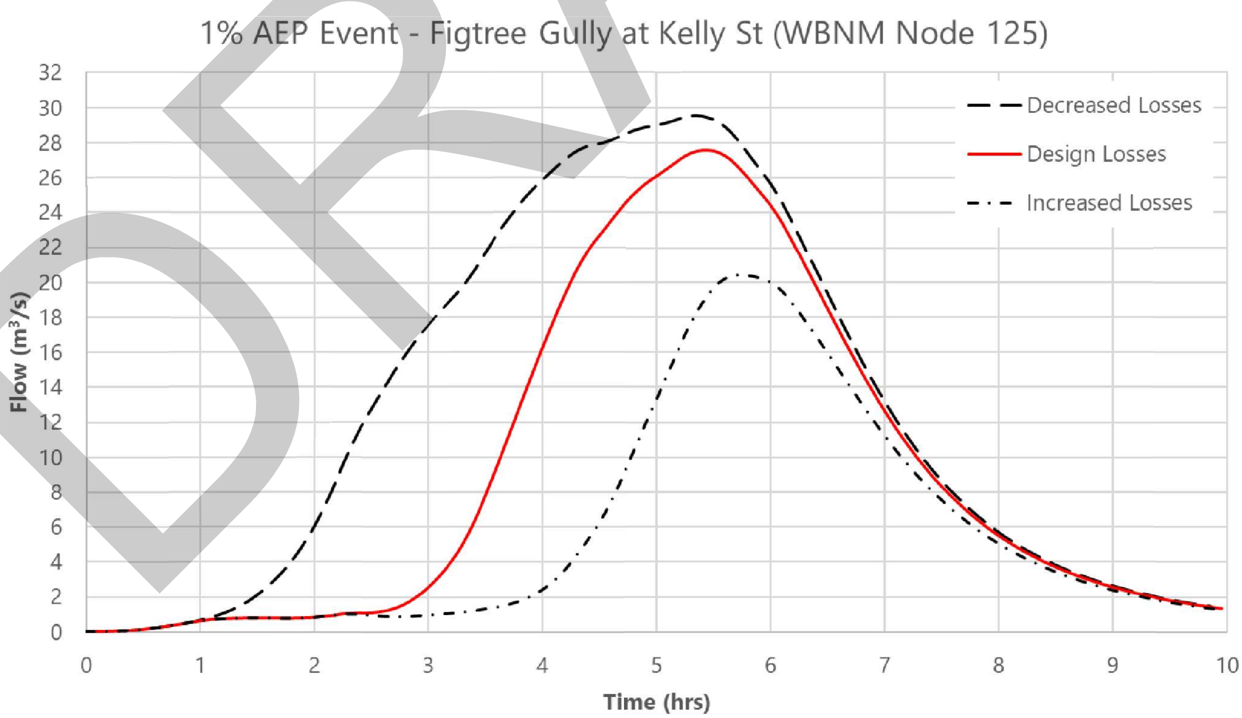


Figure B 10 1% AEP rainfall loss sensitivity analysis along Figtree Gully at Kelly Street

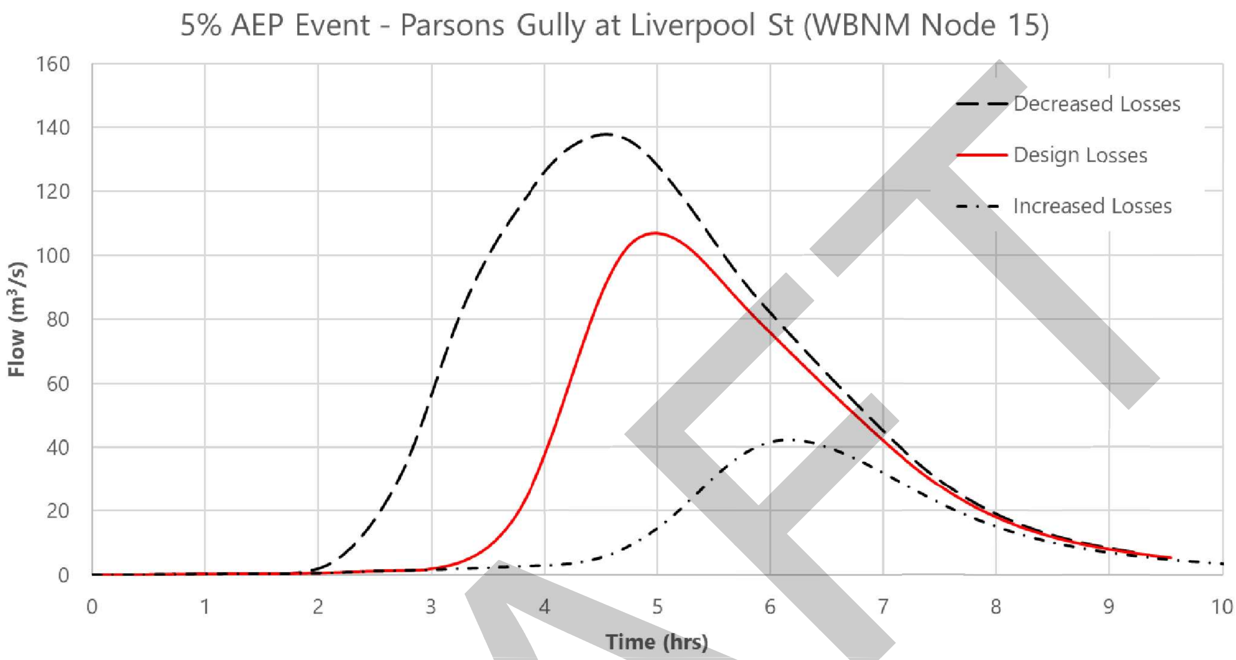


Figure B 11 5% AEP rainfall loss sensitivity analysis along Parsons Gully at Liverpool Street

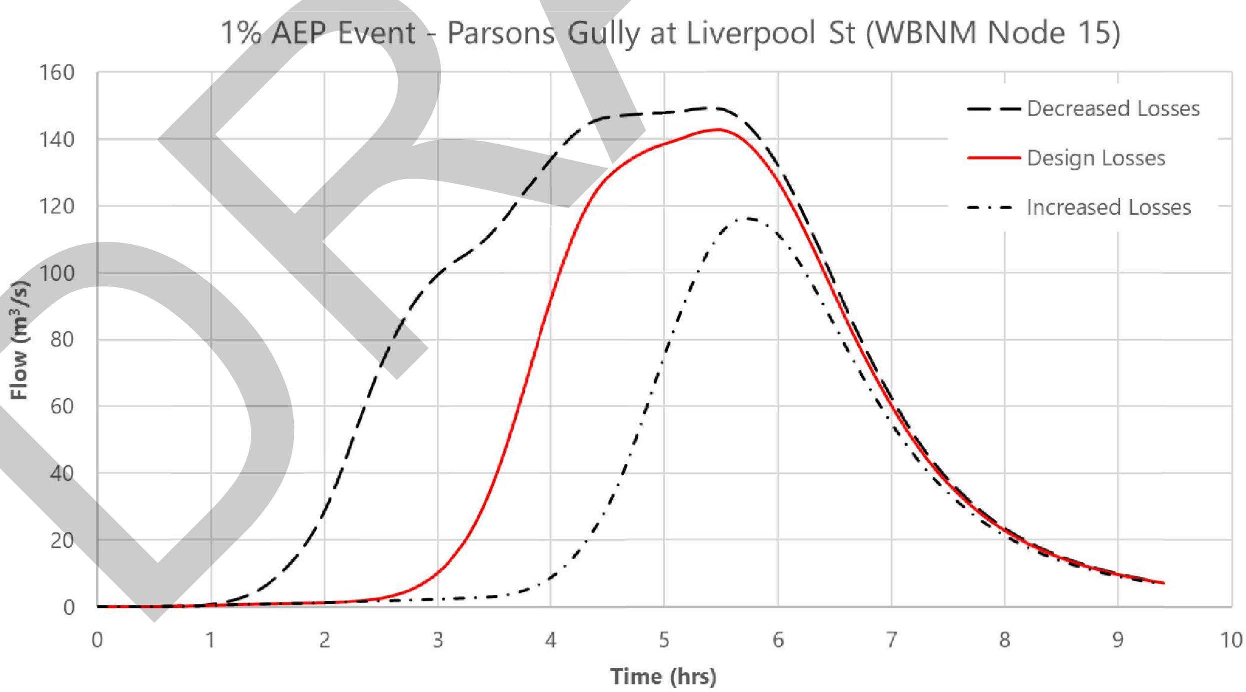


Figure B 12 1% AEP rainfall loss sensitivity analysis along Parsons Gully at Liverpool Street

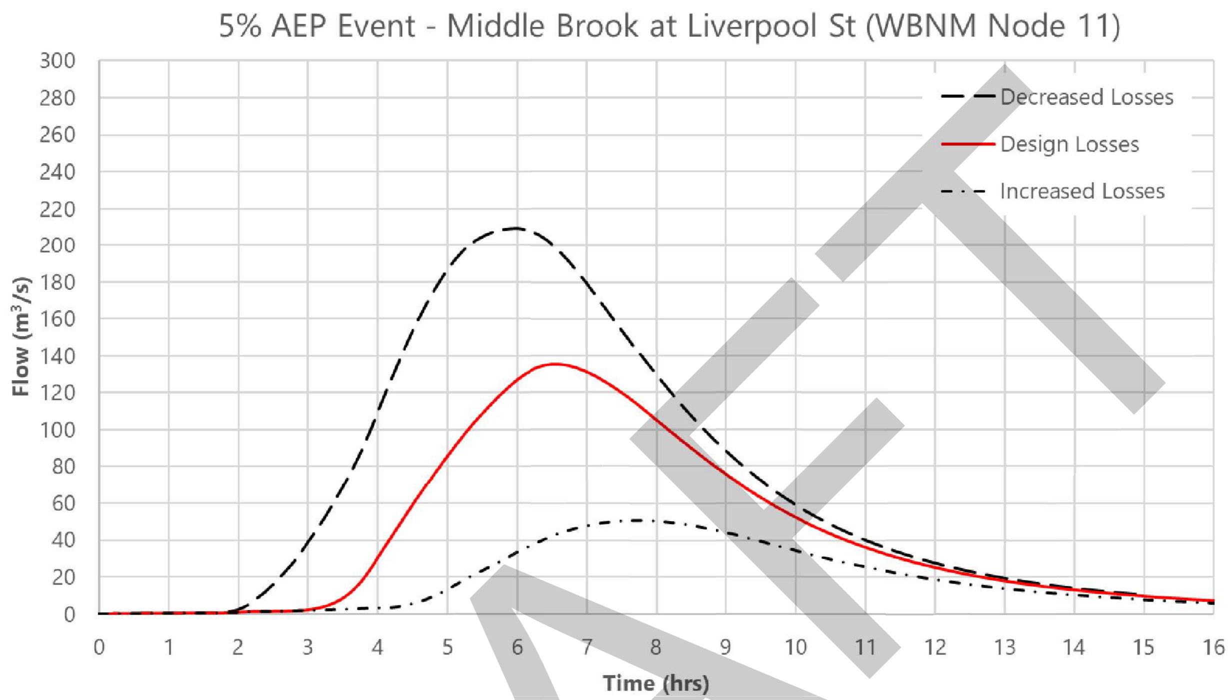


Figure B 13 5% AEP rainfall loss sensitivity analysis along Middle Brook at Liverpool Street

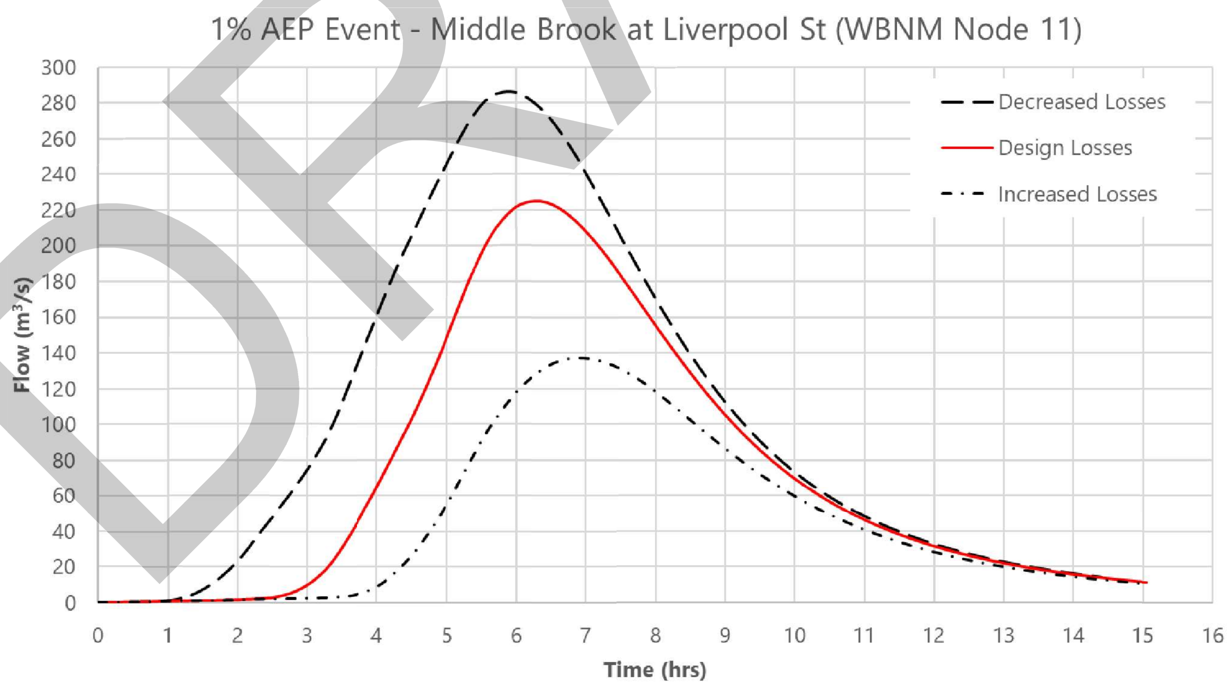


Figure B 14 1% AEP rainfall loss sensitivity analysis along Middle Brook at Liverpool Street

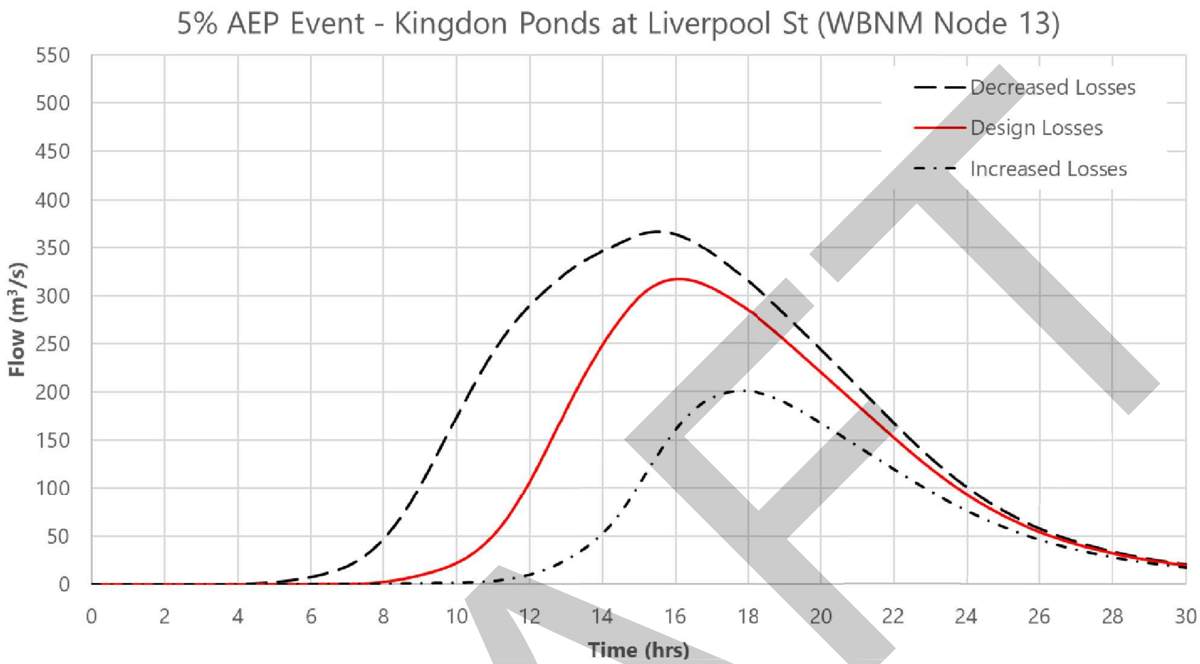


Figure B 15 5% AEP rainfall loss sensitivity analysis along Kingdon Ponds at Liverpool Street

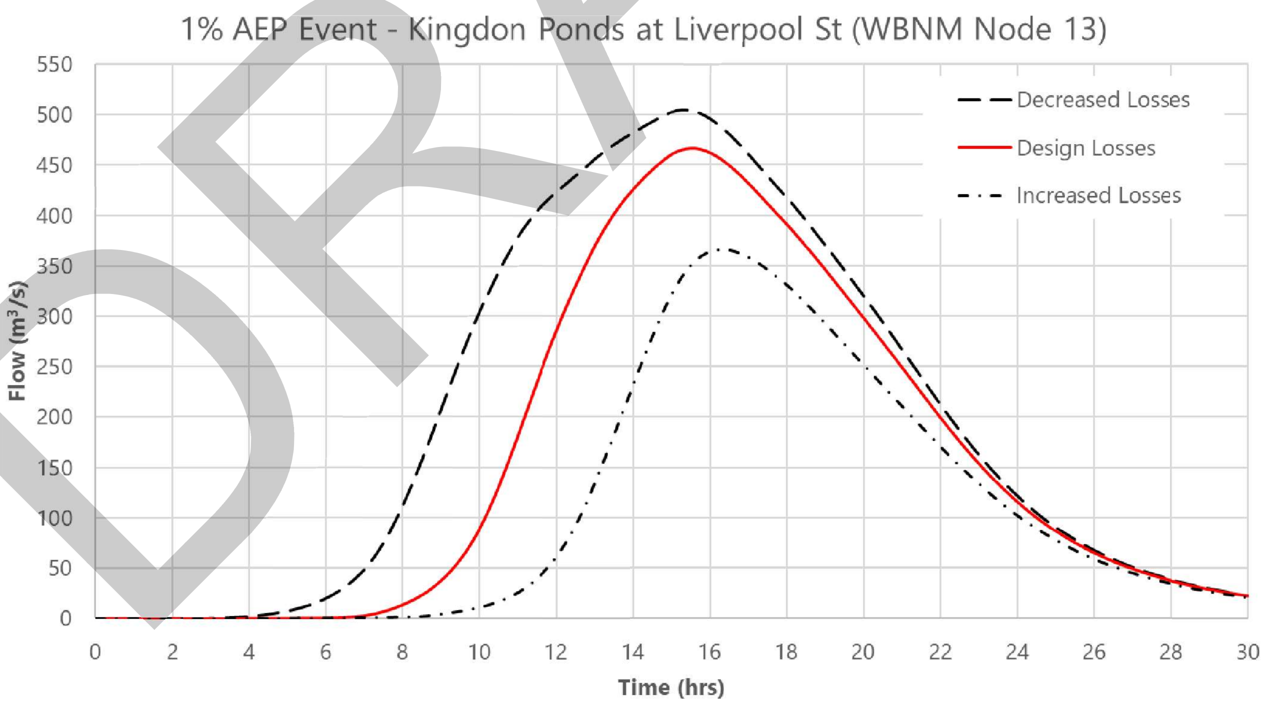


Figure B 16 1% AEP rainfall loss sensitivity analysis along Kingdon Ponds at Liverpool Street

Appendix C
Hydraulic Model Results

Prepared by: worley consulting

UPPER HUNTER SHIRE COUNCIL

LOCATIONS FOR EXTRACTION OF MODEL RESULTS

Table C 1 Summary of Peak Flood Depths

ID	Location	Peak Design Flood Depth (m)							
		20% AEP	10% AEP	5% AEP	2% AEP	1% AEP	1 in 200 AEP	1 in 500 AEP	PMF
1	Barton Street crossing of Figtree Gully	0.34	0.35	0.39	0.44	0.46	0.51	0.57	1.32
2	Oxford Road crossing of Figtree Gully	0.64	0.68	0.77	0.89	0.94	1.03	1.12	2.03
3	Waverley Street crossing of Figtree Gully	0.61	0.66	0.70	0.76	0.79	0.84	0.89	1.50
4	Park Street crossing of Figtree Gully	1.17	1.23	1.33	1.45	1.49	1.60	1.69	2.75
5	Intersection of Main St and St Aubins St near Figtree Gully	0.15	0.19	0.27	0.37	0.39	0.49	0.57	1.39
6	Intersection of Liverpool Street and Kelly Street in Scone CBD	0.18	0.26	0.38	0.48	0.50	0.61	0.72	2.17
7	Kelly Street near Commonwealth Bank in Scone CBD	0.11	0.22	0.37	0.48	0.49	0.59	0.70	2.07
8	Kingdon Street crossing of Figtree Gully	N/A	0.06	0.07	0.08	0.08	0.09	0.11	0.80
9	Parsons Gully crossing of Kingdon Street	2.16	2.42	2.60	2.78	2.94	3.08	3.25	6.64
10	Residential lots on western side of Aberdeen Street south of Liverpool Street	0.62	0.88	1.08	1.27	1.44	1.61	1.79	5.64
11	Lots on floodplain north of Liverpool Street (near Morse St)	0.40	0.51	0.59	0.68	0.83	0.97	1.15	5.06
12	Lots on floodplain south of Liverpool Street (near Wingen St)	0.30	0.35	0.57	0.81	1.01	1.21	1.44	5.96

Table C 2 Summary of Peak Flood Levels

ID	Location	Peak Design Flood Level (mAHD)							
		20% AEP	10% AEP	5% AEP	2% AEP	1% AEP	1 in 200 AEP	1 in 500 AEP	PMF
1	Barton Street crossing of Figtree Gully	232.99	233.01	233.04	233.09	233.12	233.16	233.22	233.97
2	Oxford Road crossing of Figtree Gully	222.02	222.07	222.16	222.28	222.33	222.42	222.51	223.42
3	Waverley Street crossing of Figtree Gully	219.20	219.24	219.29	219.35	219.37	219.42	219.47	220.09
4	Park Street crossing of Figtree Gully	215.50	215.56	215.66	215.78	215.82	215.92	216.02	217.08
5	Intersection of Main St and St Aubins St near Figtree Gully	212.84	212.88	212.96	213.06	213.08	213.17	213.26	214.08
6	Intersection of Liverpool Street and Kelly Street in Scone CBD	209.00	209.08	209.20	209.30	209.32	209.43	209.54	210.99
7	Kelly Street near Commonwealth Bank in Scone CBD	208.87	208.99	209.13	209.24	209.25	209.36	209.47	210.83
8	Kingdon Street crossing of Figtree Gully	N/A	204.60	204.61	204.63	204.63	204.63	204.65	205.34
9	Parsons Gully crossing of Kingdon Street	200.42	200.67	200.86	201.04	201.20	201.34	201.51	204.90
10	Residential lots on western side of Aberdeen Street south of Liverpool Street	200.50	200.77	200.96	201.15	201.33	201.49	201.68	205.53
11	Lots on floodplain north of Liverpool Street (near Morse St)	201.92	202.03	202.10	202.19	202.34	202.49	202.67	206.57
12	Lots on floodplain south of Liverpool Street (near Wingen St)	200.97	201.02	201.25	201.48	201.69	201.88	202.11	206.63

Table C 3 Summary of Peak Flow Velocities

ID	Location	Peak Design Flow Velocities (m/s)							
		20% AEP	10% AEP	5% AEP	2% AEP	1% AEP	1 in 200 AEP	1 in 500 AEP	PMF
1	Barton Street crossing of Figtree Gully	1.61	1.68	1.79	1.94	2.00	2.13	2.29	3.41
2	Oxford Road crossing of Figtree Gully	1.20	1.29	1.43	1.60	1.66	1.78	1.93	2.87
3	Waverley Street crossing of Figtree Gully	1.52	1.53	1.72	2.06	2.16	2.35	2.54	3.88
4	Park Street crossing of Figtree Gully	1.08	1.07	1.05	1.08	1.08	1.10	1.12	1.50
5	Intersection of Main St and St Aubins St near Figtree Gully	0.97	1.00	1.04	1.16	1.22	1.44	1.64	2.55
6	Intersection of Liverpool Street and Kelly Street in Scone CBD	0.54	0.60	0.60	0.68	0.69	0.84	1.09	2.50
7	Kelly Street near Commonwealth Bank in Scone CBD	0.45	0.47	0.50	0.50	0.53	0.56	0.63	1.00
8	Kingdon Street crossing of Figtree Gully	0.00	0.81	1.02	1.15	1.16	1.20	1.24	1.65
9	Parsons Gully crossing of Kingdon Street	1.08	1.29	1.43	1.57	1.70	1.81	1.95	4.27
10	Residential lots on western side of Aberdeen Street south of Liverpool Street	0.06	0.08	0.09	0.16	0.15	0.19	0.21	0.28
11	Lots on floodplain north of Liverpool Street (near Morse St)	0.89	1.09	1.16	1.17	1.30	1.24	1.33	1.17
12	Lots on floodplain south of Liverpool Street (near Wingen St)	0.10	0.12	0.12	0.12	0.12	0.13	0.14	0.55

DRAFT